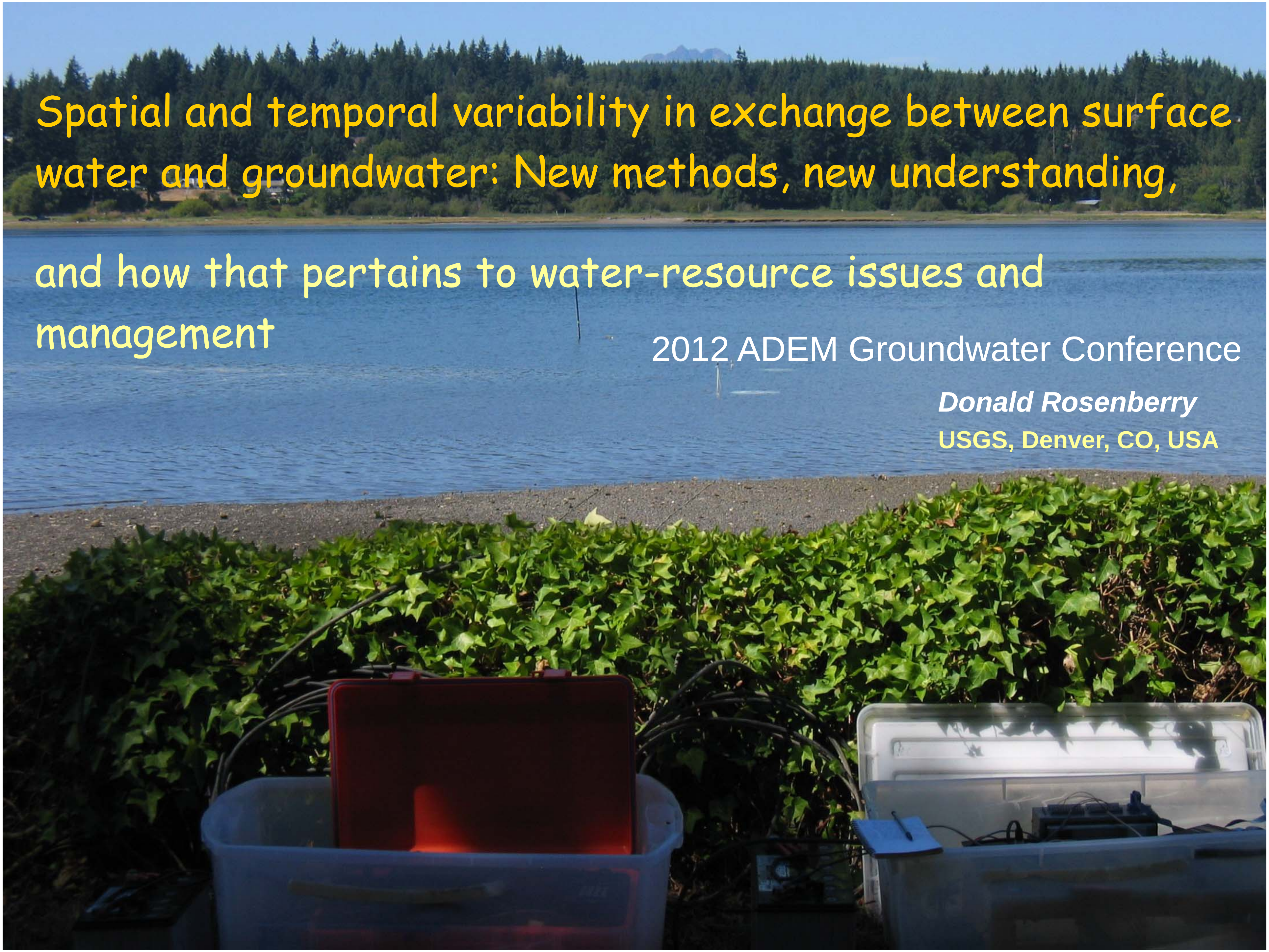
Spatial and temporal variability in exchange between surface water and groundwater: New methods, new understanding,

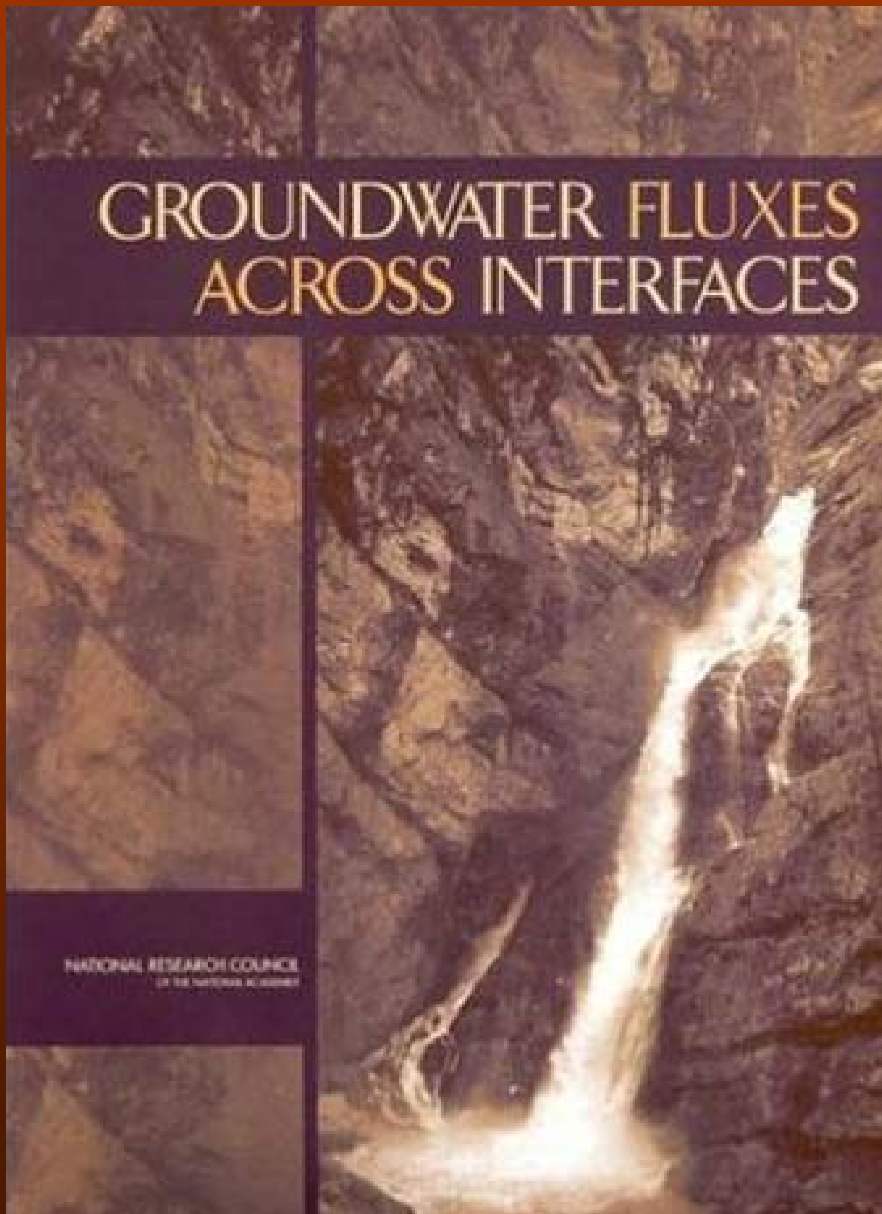
and how that pertains to water-resource issues and management

2012 ADEM Groundwater Conference

Donald Rosenberry

USGS, Denver, CO, USA





Why?

NRC Committee – New/recent challenges

COMMITTEE ON HYDROLOGIC SCIENCE[1]

ERIC F. WOOD, *Chair*, Princeton University, Princeton, New Jersey
MARY P. ANDERSON, University of Wisconsin, Madison
VICTOR R. BAKER, University of Arizona, Tucson
DARA ENTEKHABI, Massachusetts Institute of Technology, Cambridge (through December 31, 2002)
NANCY B. GRIMM, Arizona State University, Tempe
GEORGE M. HORNBERGER, University of Virginia, Charlottesville
DENNIS P. LETTENMAIER, University of Washington, Seattle
WILLIAM K. NUTTLE, Consultant, Ottawa, Ontario, Canada (through December 31, 2002)
KENNETH W. POTTER, University of Wisconsin, Madison (through December 31, 2002)
JOHN O. ROADS, Scripps Institution of Oceanography, La Jolla, California (through December 31, 2002)
JOHN L. WILSON, New Mexico Tech, Socorro, New Mexico

NRC Staff

WILLIAM S. LOGAN, Project Director, Water Science and Technology Board
ANITA A. HALL, Senior Project Assistant, Water Science and Technology Board

USGS
science for a changing world

National Research Council Major Findings

1. Our ability to quantify spatial and temporal variability in recharge and discharge is inadequate and must be improved.
2. The roles of groundwater storage, and recharge and discharge fluxes in the climate system are poorly understood.
3. Better measurements are needed as well as better ways to scale measurements

USGS
science for a changing world

Spatial variability

Local-scale heterogeneity

- Interlayering of sand and organics
- Trapped gas
- Vegetation zones
- Stage changes – shoreline movements
- Anthropogenic effects (veg. removal, veg. enhancement, beaches, prop wash)
- Stream meanders, hyporheic effects

Geological controls

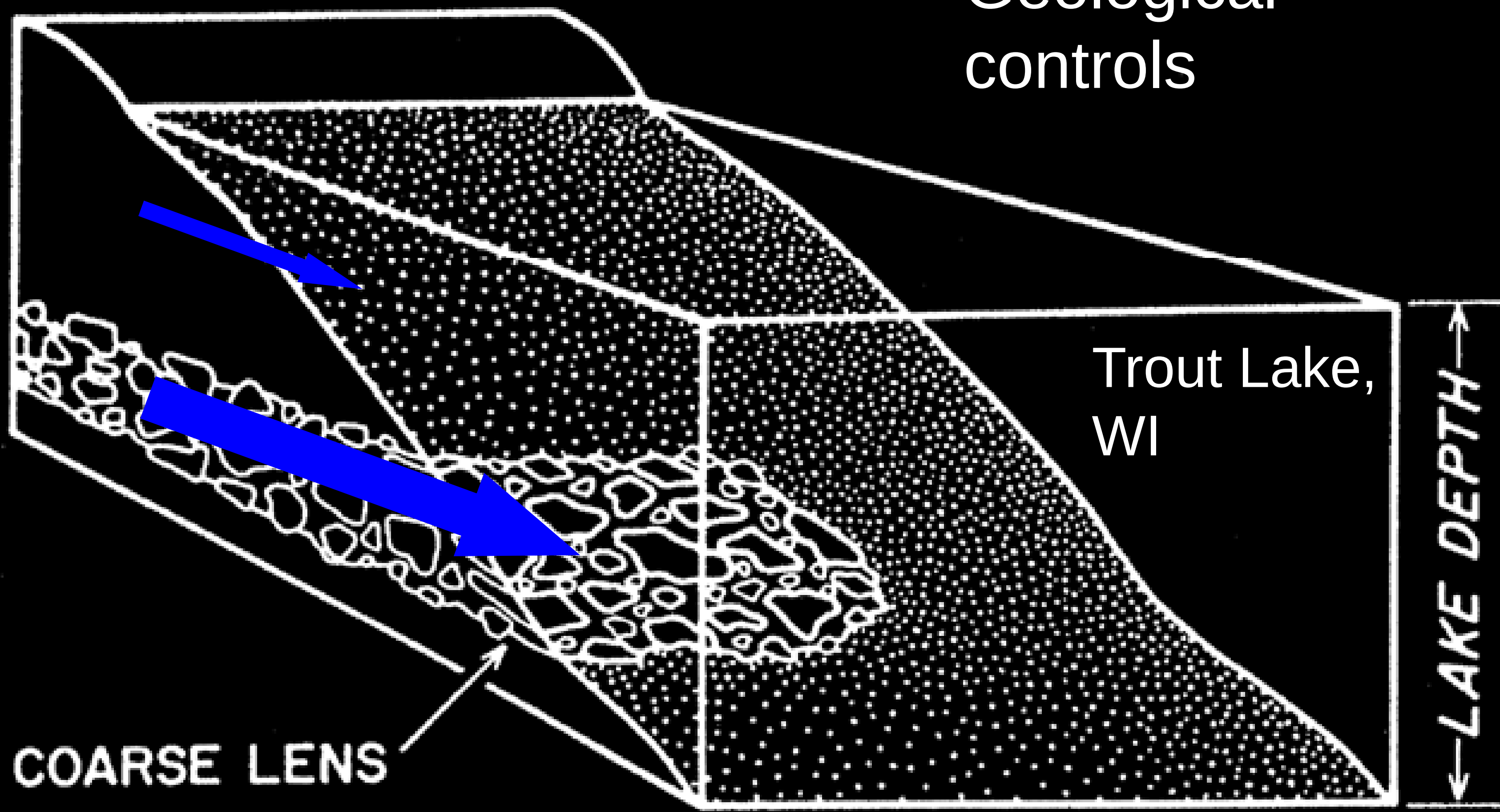
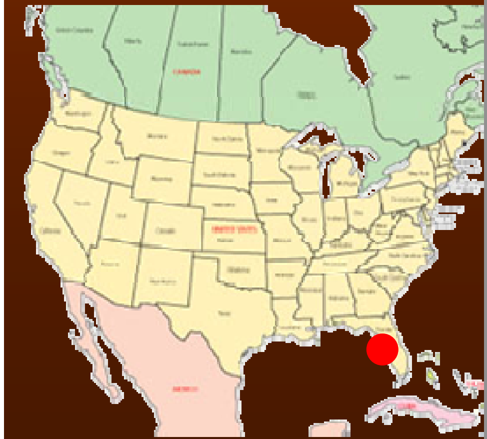


Fig. 5. Three-dimensional schematic drawing of the hypothesized situation at Trout Lake showing a coarse lens intersecting the lakebed.

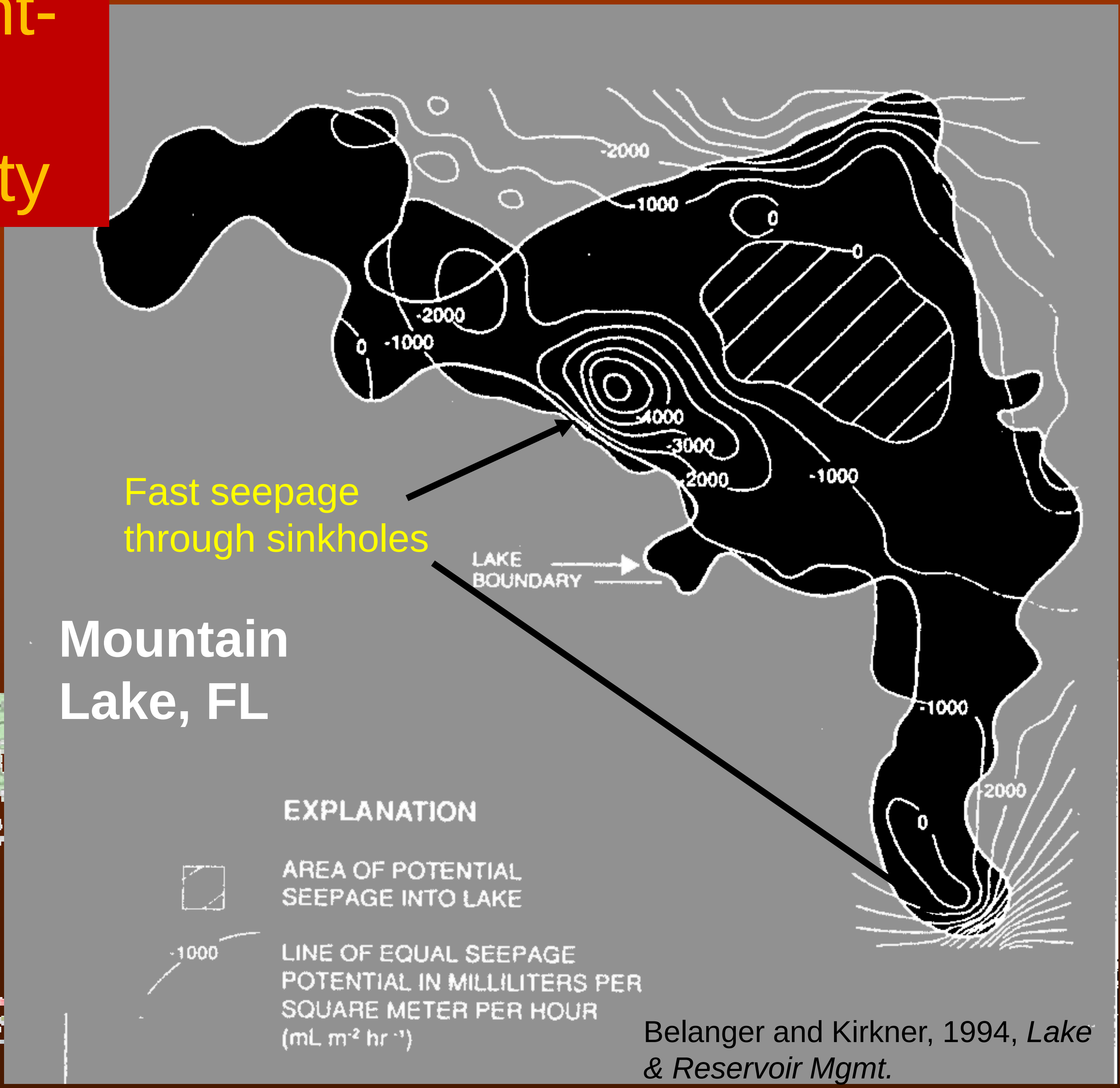
Krabbenhoft and Anderson, 1986, *Ground Water*

Management-scale heterogeneity

Geological controls

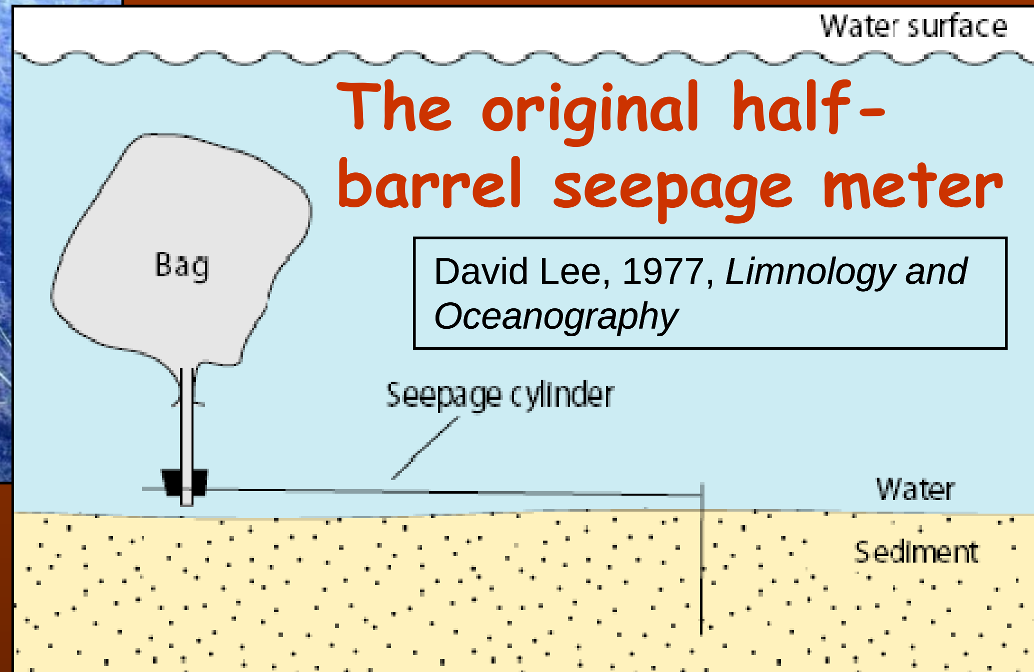


Mountain Lake, FL



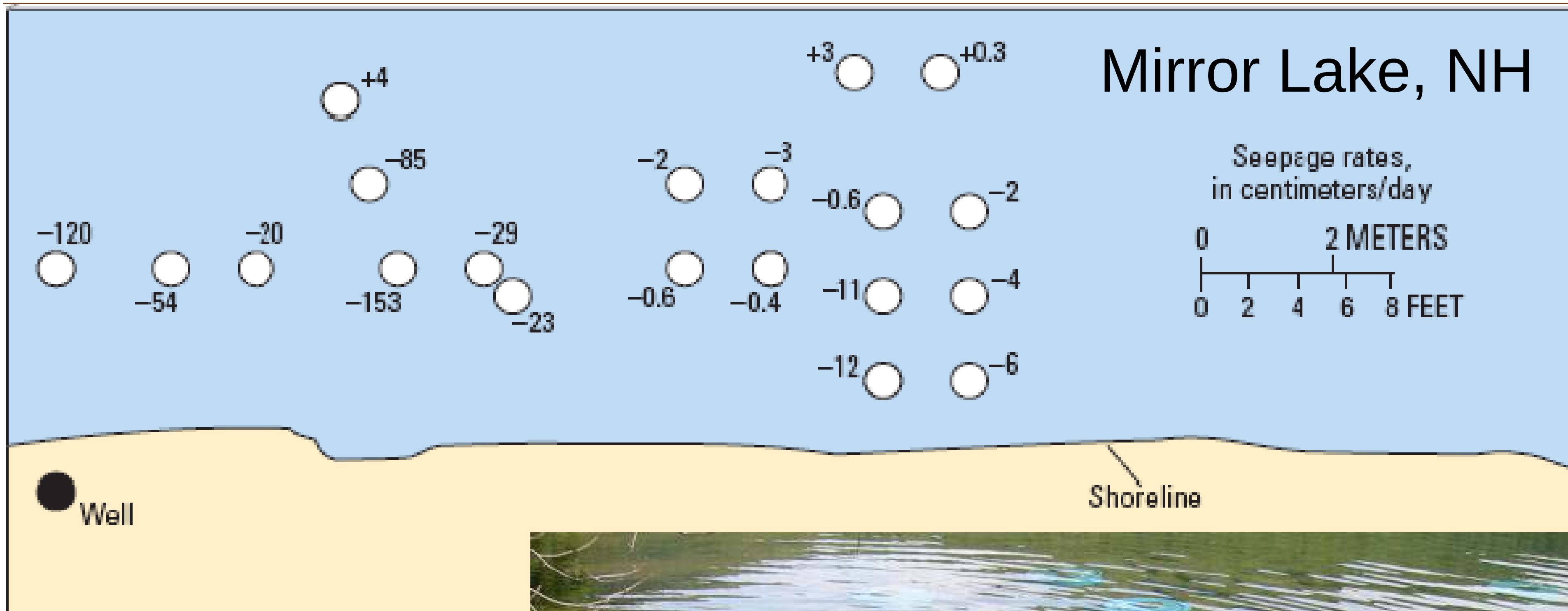
Belanger and Kirkner, 1994, *Lake & Reservoir Mgmt.*

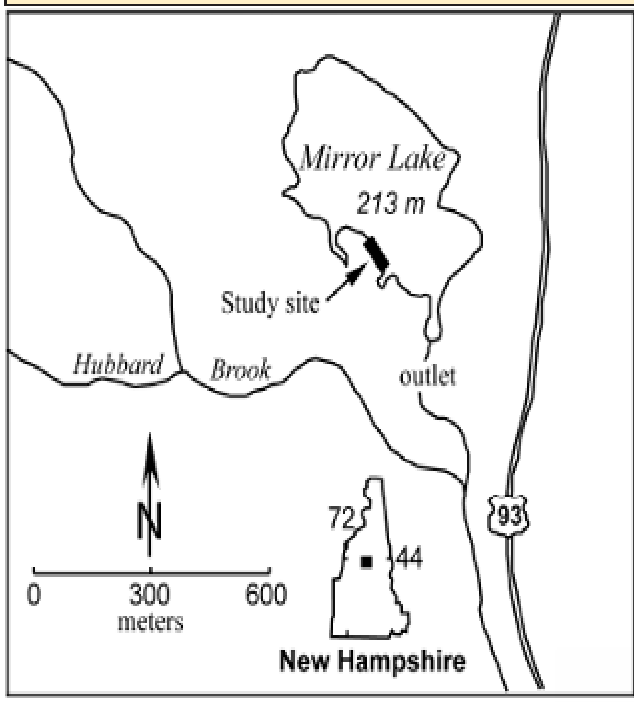
How?



- Direct measurement of flux
- Measure flows from ~0.1 to ~500 cm/d (10^{-8} to 5x10^{-5} m/s)
- Modified versions can measure down to ~0.00001 cm/d or up to 5000 cm/d or more

Mirror Lake, NH

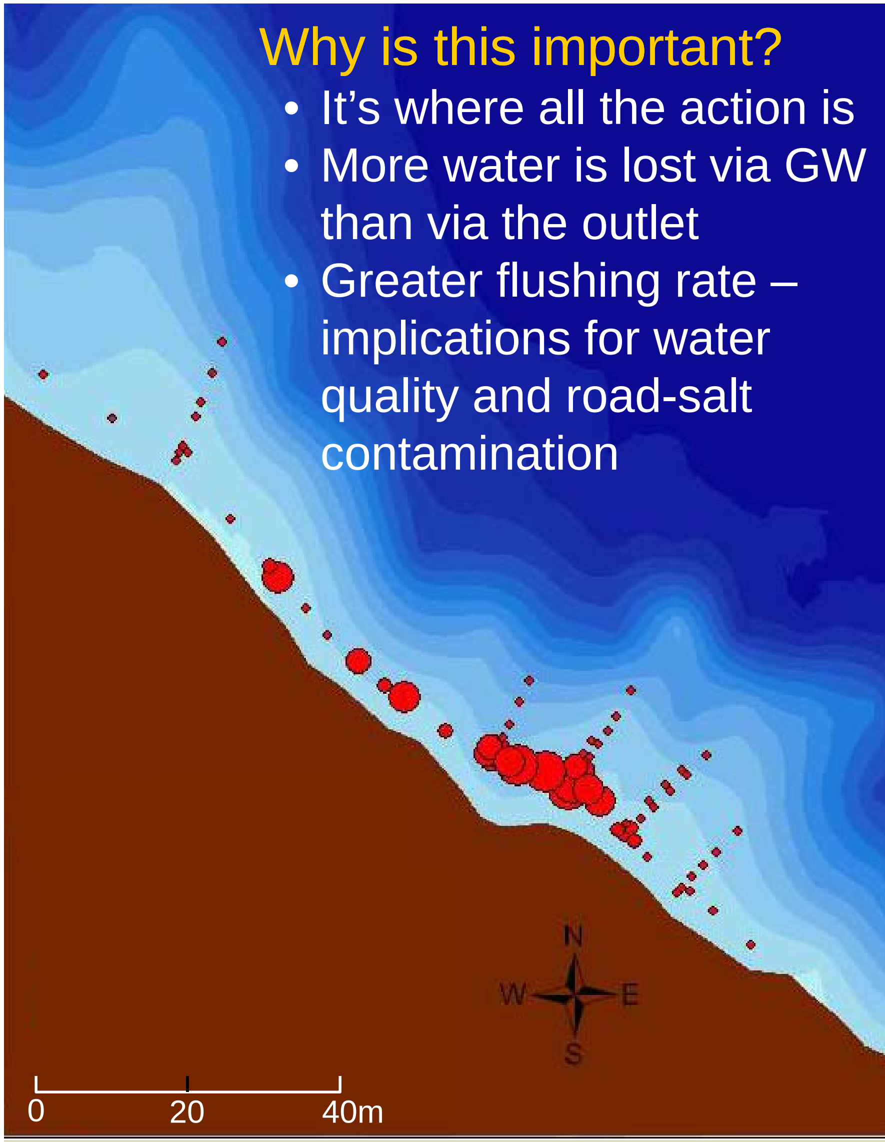


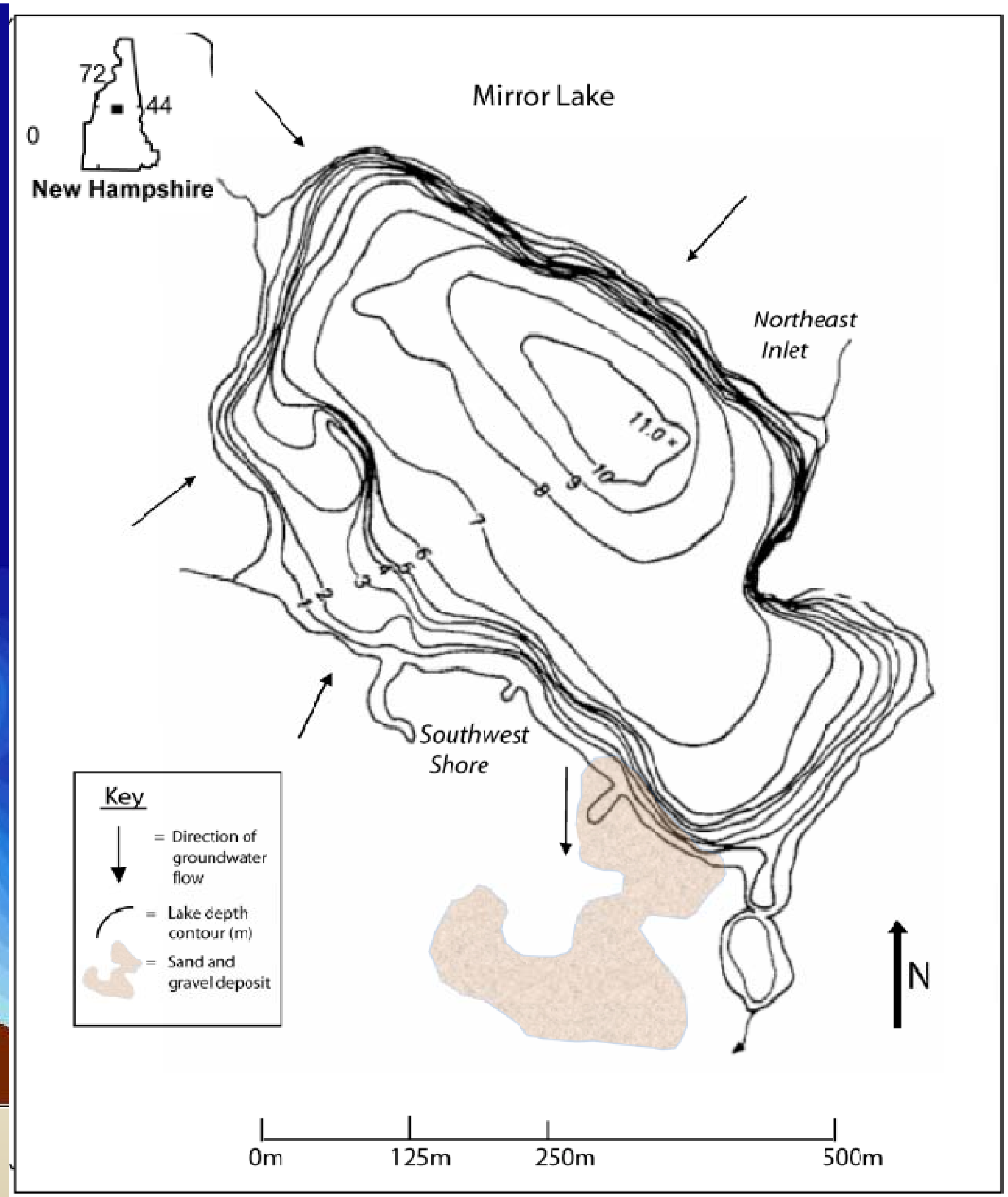


Rosenberry, 2005, *Limnology and Oceanography-Methods*.

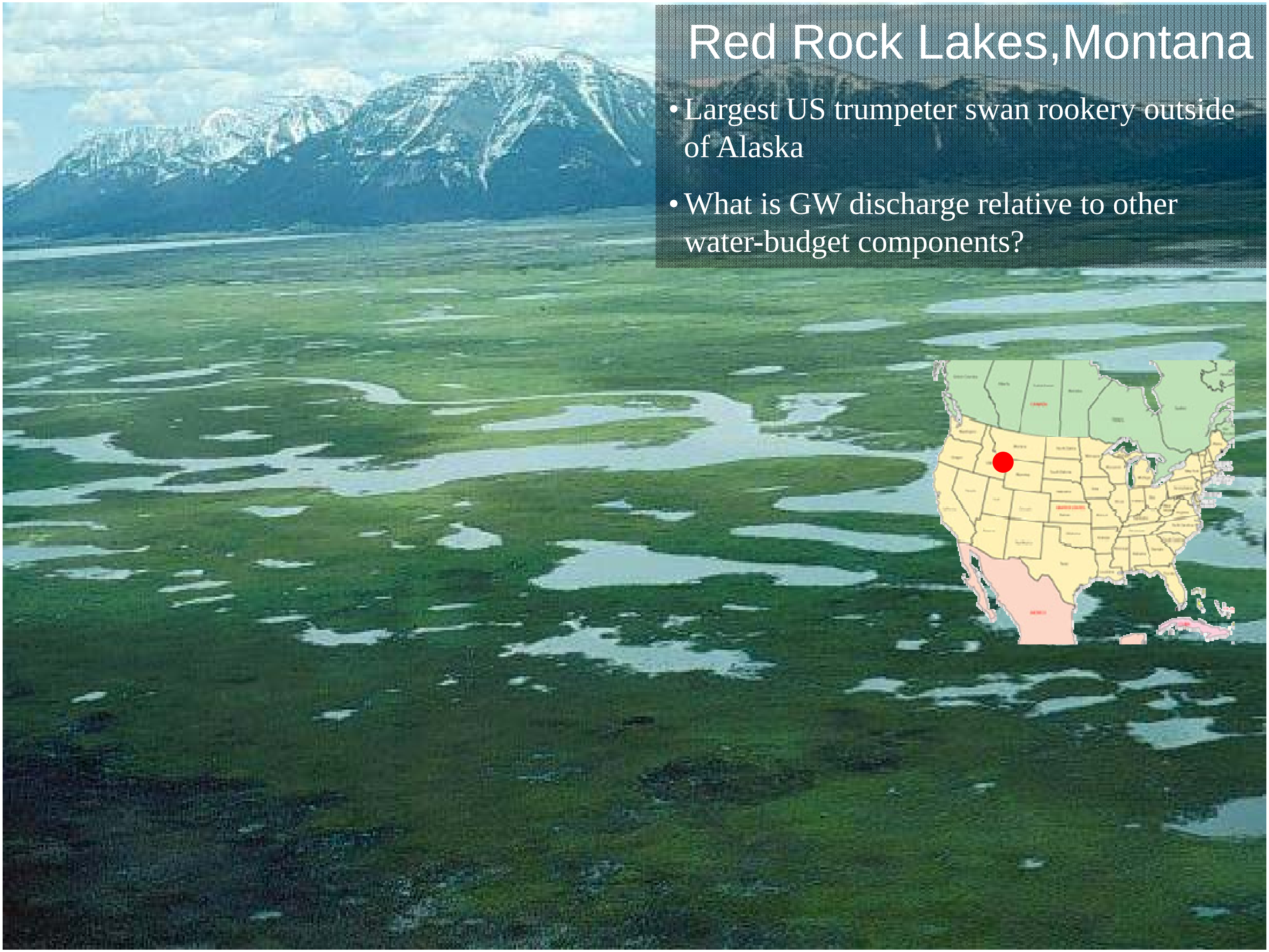
Why is this important?

- It's where all the action is
- More water is lost via GW than via the outlet
- Greater flushing rate – implications for water quality and road-salt contamination

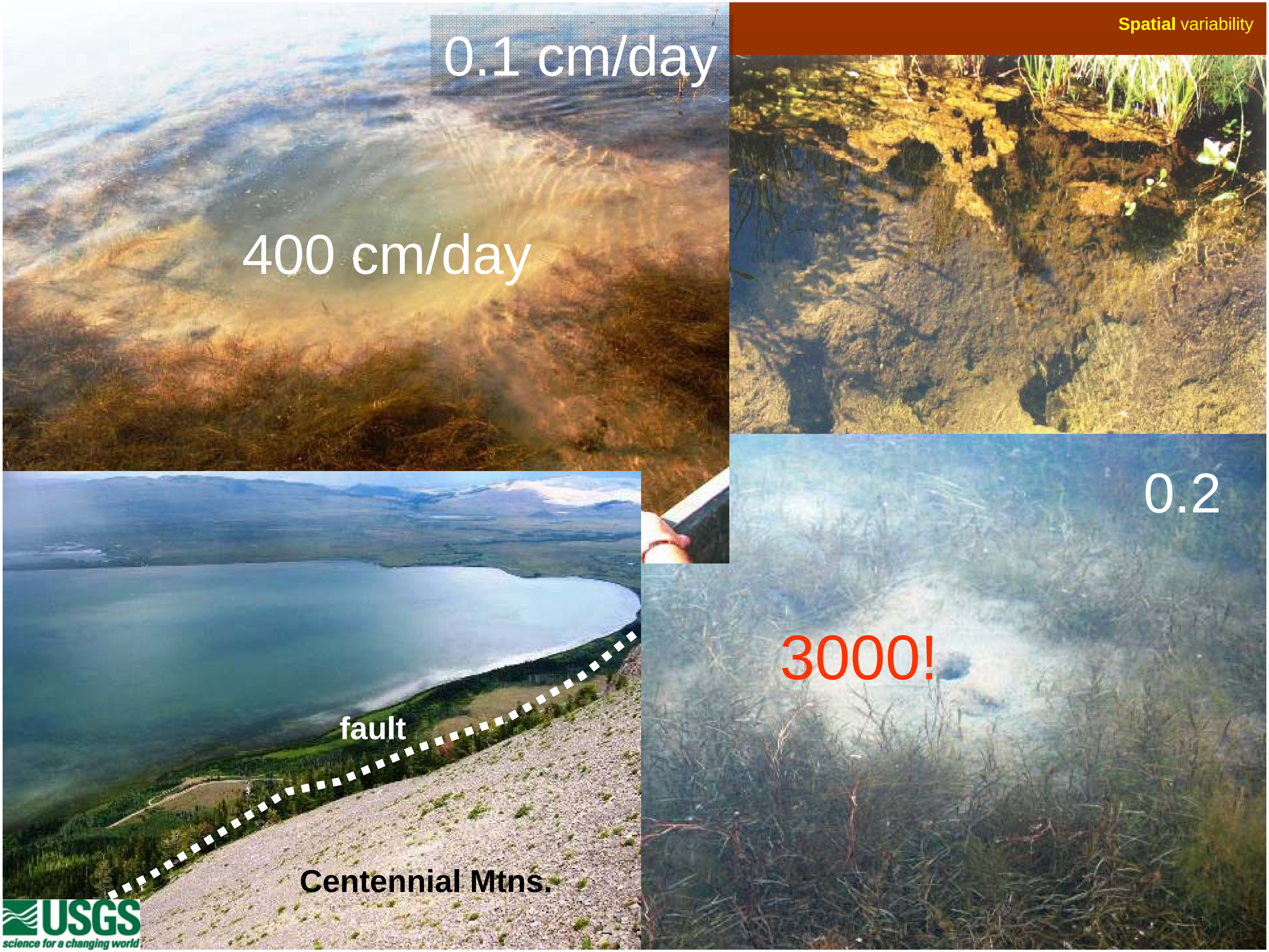




Gagliano et al., 2009, *SAGEEP*
Mitchell et al., 2008, *SAGEEP*
Rosenberry, 2005, *L&O-Methods*
Rosenberry & Morin, 2004, *Ground Water*

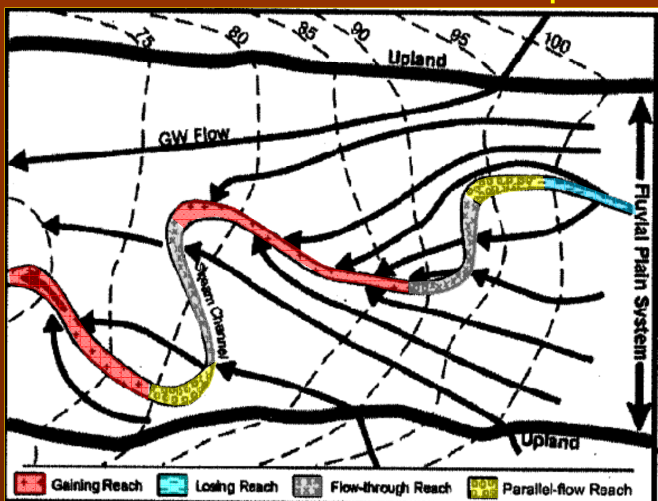

Red Rock Lakes,Montana
• Largest US trumpeter swan rookery outside of Alaska
• What is GW discharge relative to other water-budget components?

Spatial variability



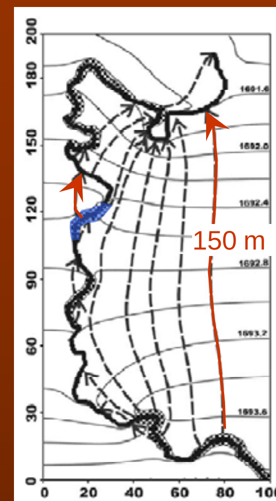
Heterogeneity is a bigger problem yet in fluvial settings

floodplain



Woessner, 2000

meander



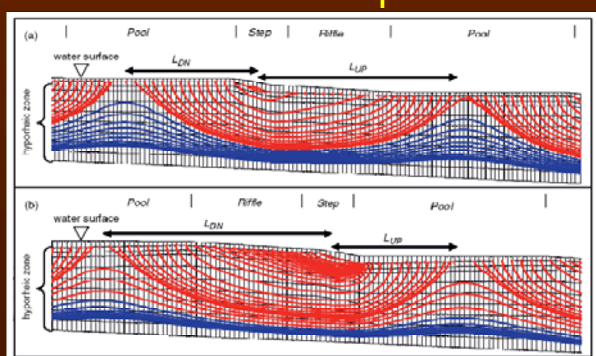
Lautz & Siegel, 2006

Donald Rosenberry

US Geological Survey

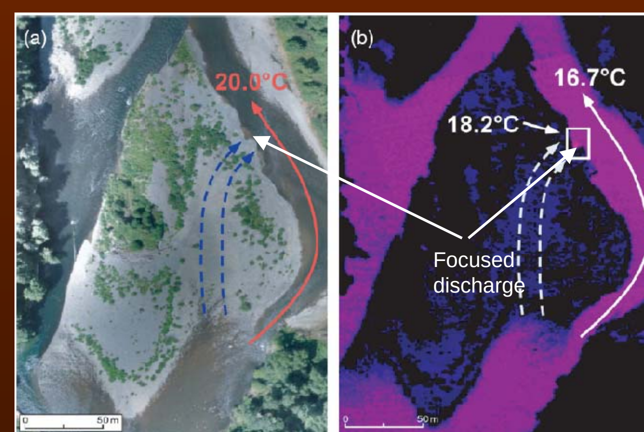
Denver, Colorado, USA

pool-riffle



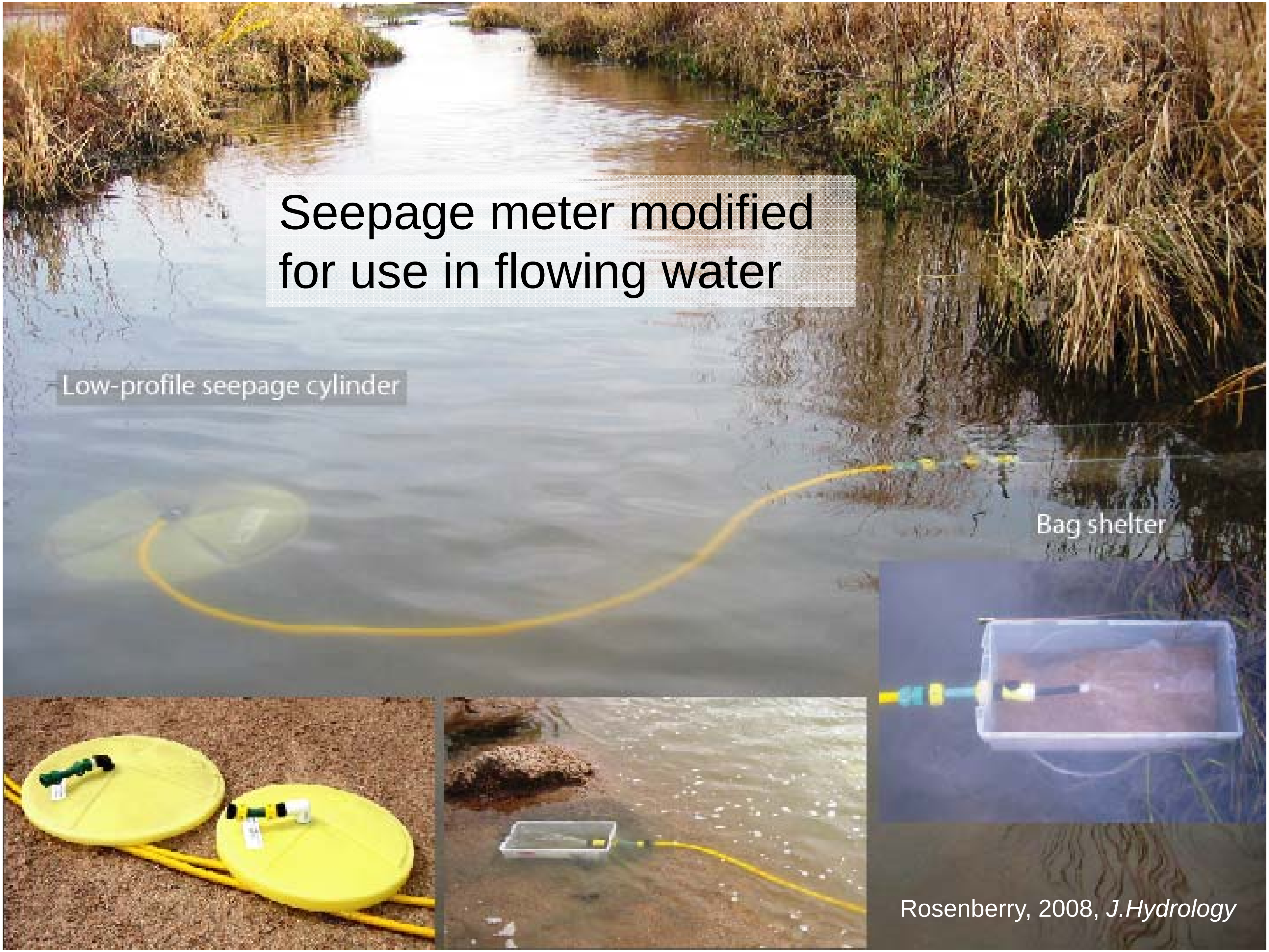
Gooseff et al., 2006

bar

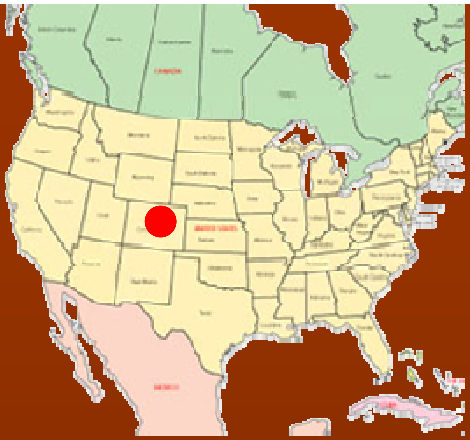


Burkholder et al., 2008

Seepage meter modified for use in flowing water

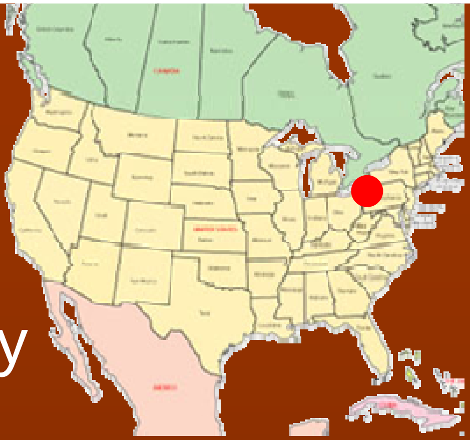


Rosenberry, 2008, *J.Hydrology*



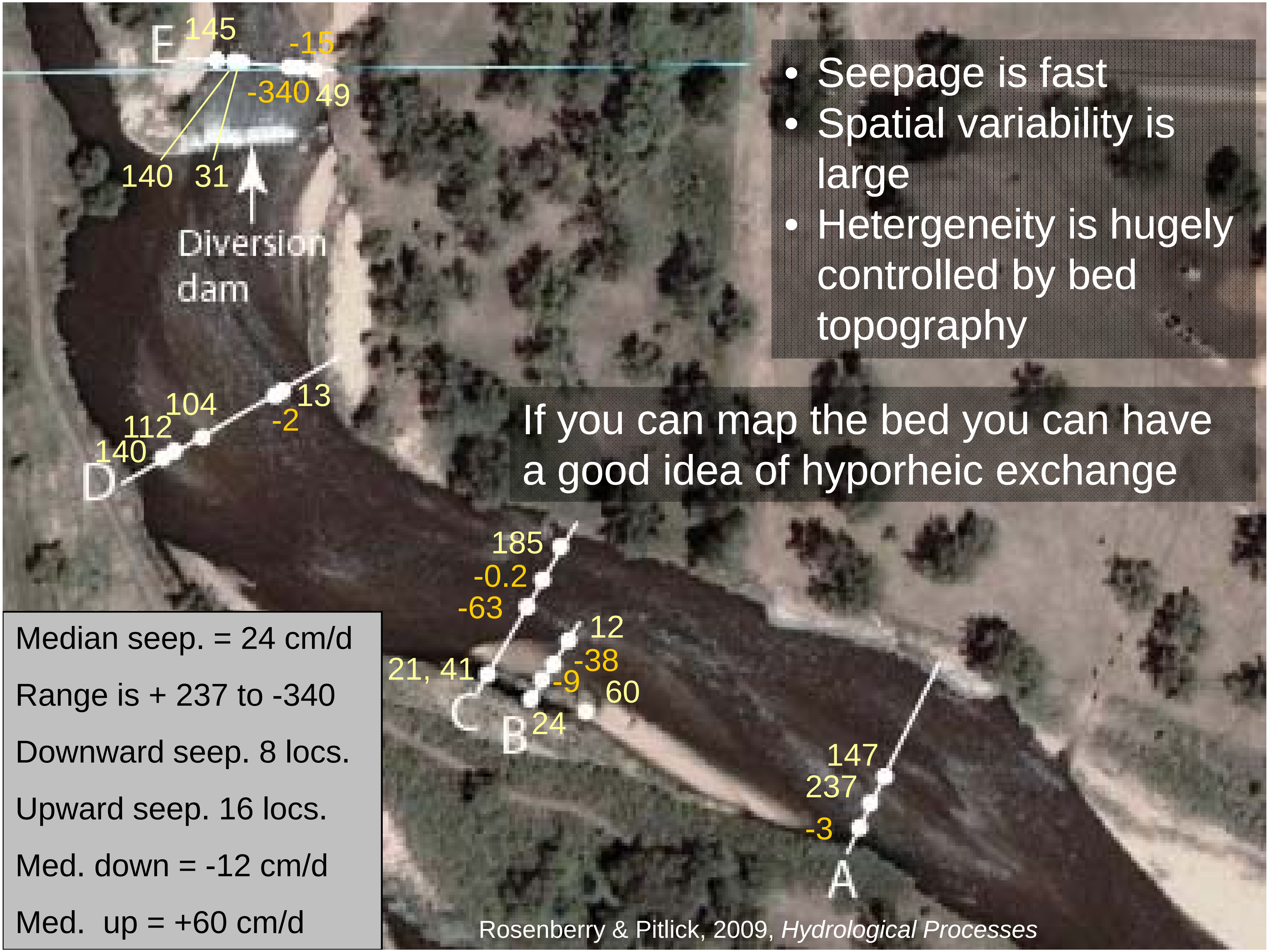
South Platte River

Allegheny River



Rosenberry & Pitlick, 2009, *Hydrol. Proc.*

Rosenberry et al., 2012, *Hydrol. Proc.*



- Seepage is fast
- Spatial variability is large
- Hetergeneity is hugely controlled by bed topography

If you can map the bed you can have a good idea of hyporheic exchange

Median seep. = 24 cm/d

Range is + 237 to -340

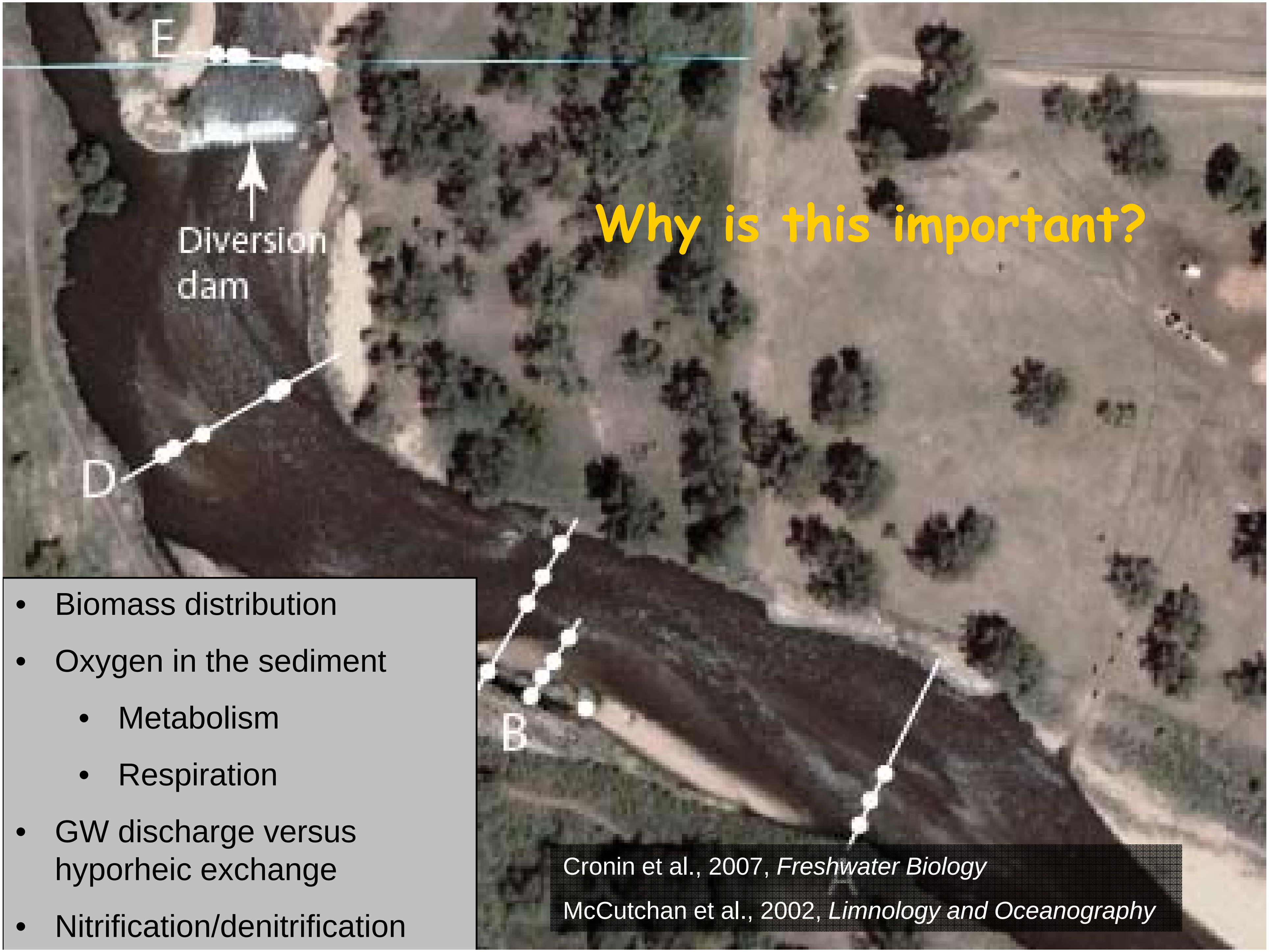
Downward seep. 8 locs.

Upward seep. 16 locs.

Med. down = -12 cm/d

Med. up = +60 cm/d

Rosenberry & Pitlick, 2009, *Hydrological Processes*



Why is this important?

- Biomass distribution
- Oxygen in the sediment
  - Metabolism
  - Respiration
- GW discharge versus hyporheic exchange
- Nitrification/denitrification

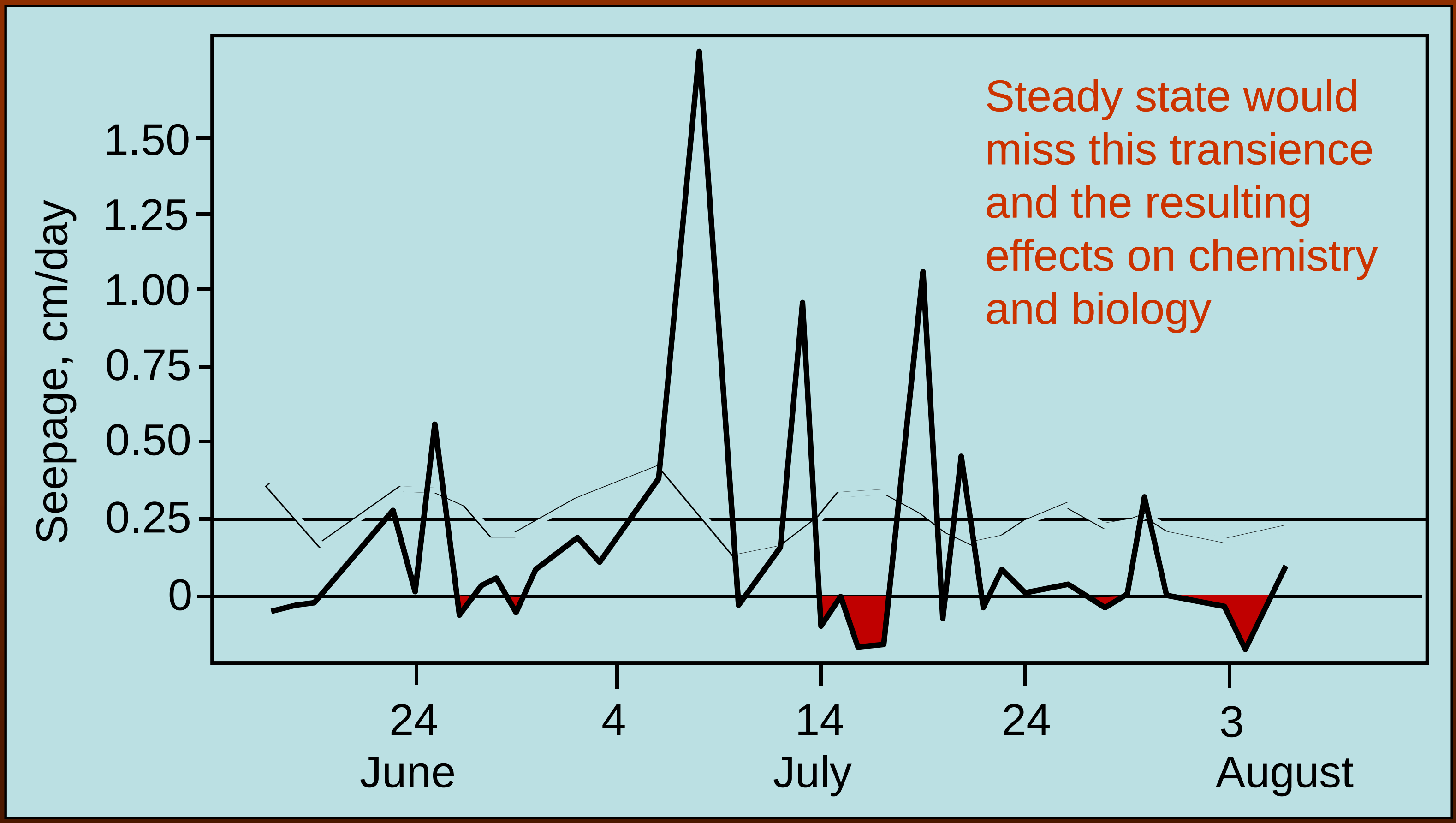
Cronin et al., 2007, *Freshwater Biology*

McCutchan et al., 2002, *Limnology and Oceanography*

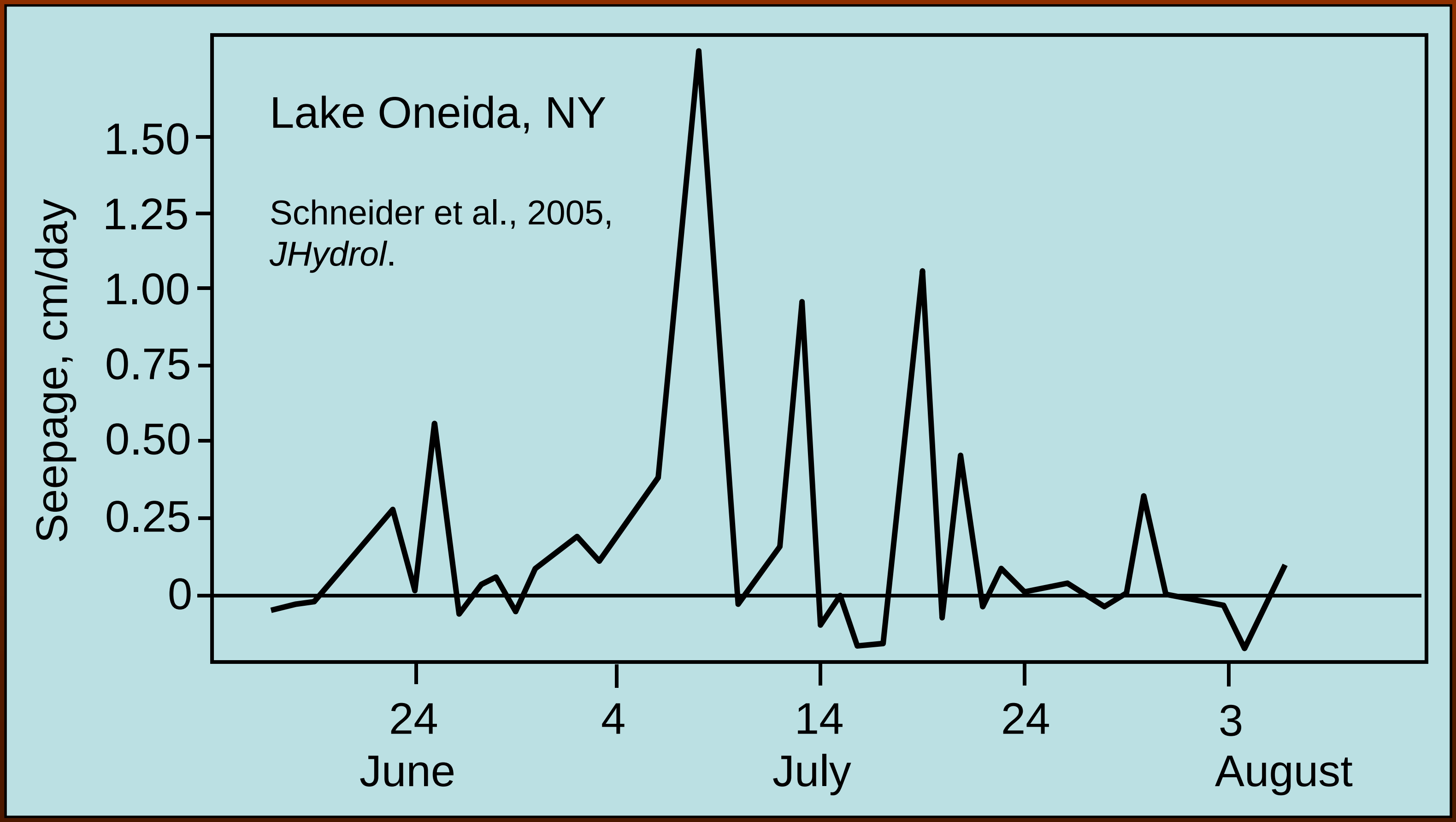
Temporal variability

Temporal variability affects

- Physical conditions in the substrate
- Geochemistry
- Biology



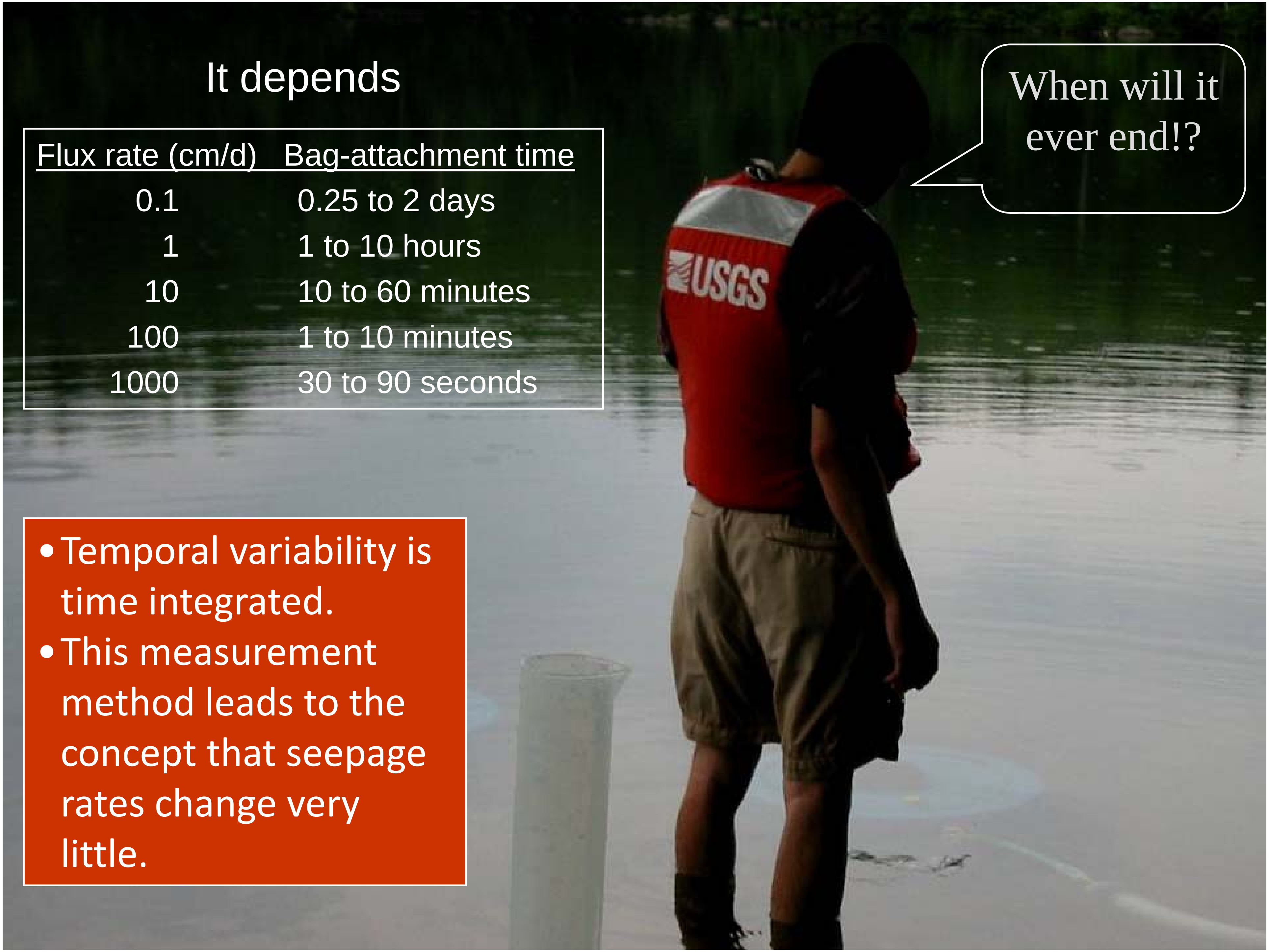
But does this matter?
and if so, on what temporal scale?



It depends

Flux rate (cm/d)	Bag-attachment time
0.1	0.25 to 2 days
1	1 to 10 hours
10	10 to 60 minutes
100	1 to 10 minutes
1000	30 to 90 seconds

- Temporal variability is time integrated.
- This measurement method leads to the concept that seepage rates change very little.



	Individual seepage meter			
	S1	S2	S3	S4
Mean	18	5.2	8.7	10.6
s	3.23	0.85	0.49	2.66
n	6	6	6	6

Rosenberry, 2005, *Limnology and Oceanography-Methods*

Reinforced by averaging multiple measurements and report the mean

Table 1
Statistical Summary of Specific Discharge Data Using Adjusted 1999 Specific Discharge Measurements

	N	Median	Mean	Standard Deviation	Standard Error	CV (%)	Maximum	Minimum
All (adjusted)	341	0.25	0.34	0.31	0.02	92	1.72	−0.02
1999 (adjusted)	171	0.35	0.41	0.31	0.02	76	1.41	−0.01
2000	170	0.17	0.28	0.30	0.02	109	1.72	−0.02

Note: Values in µm/s. Negative values (*N* = 4) indicate outflow from the lake.

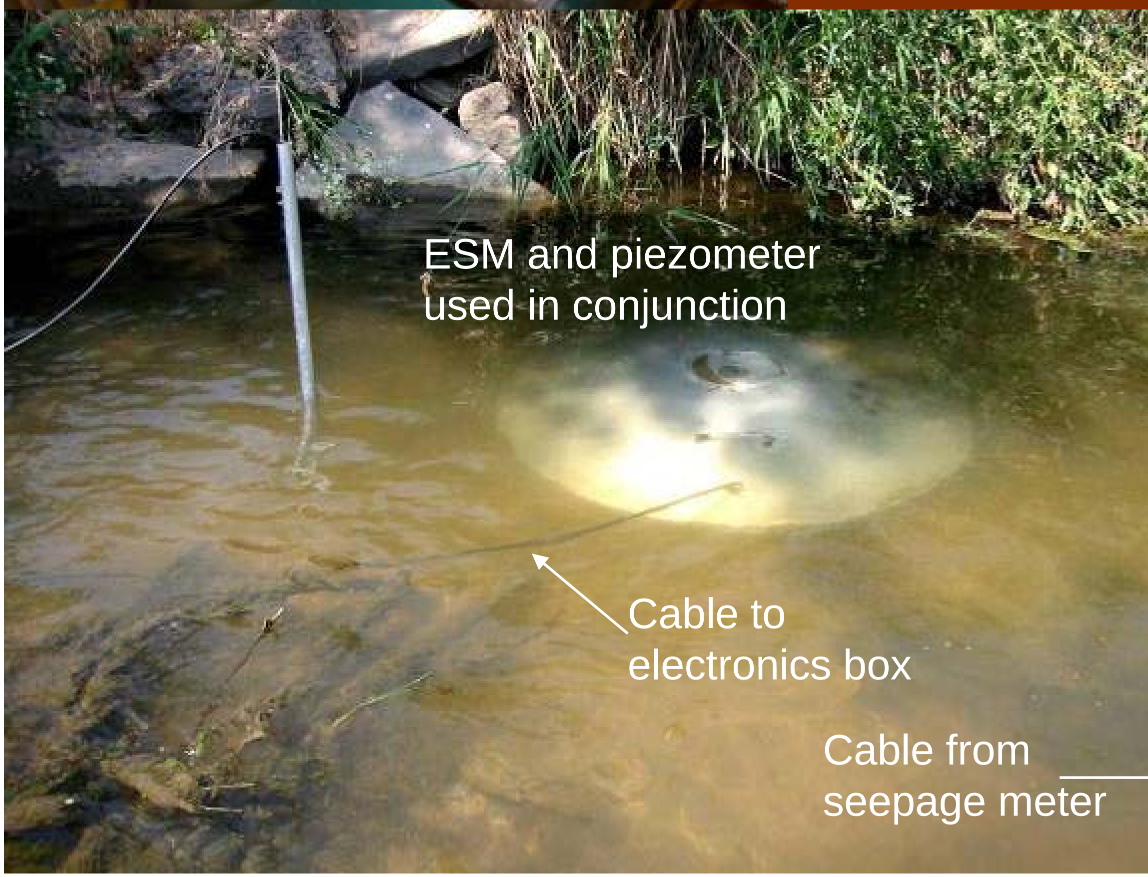
Simpkins, 2006, *Ground Water*

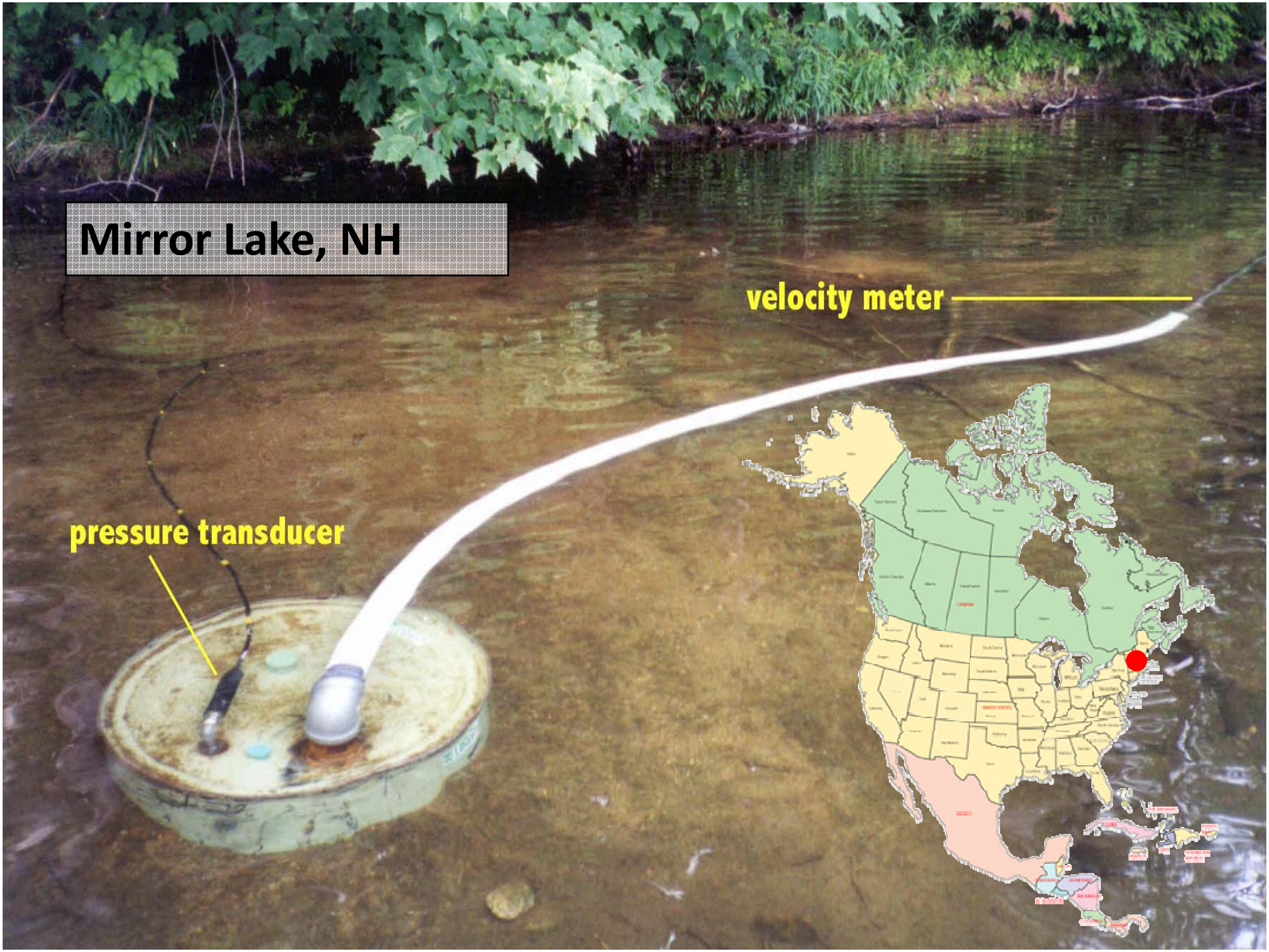
Table 1. Average seepage rates (±1σ, *n* = 3) for 4 stations in the Indian River Lagoon.

	Average Seepage (cm/day)							
	11-12 May 2003		11-12 June 2003		12-14 July 2003		25-27 Sept 2003	
Station	rate	±	rate	±	rate	±	rate	±
BRL2								
East #1	1.57	0.07	3.45	1.66	0.78	1.34	2.91	0.96
West #2	1.51	0.54	2.89	0.77	3.31	0.78	1.29	0.75

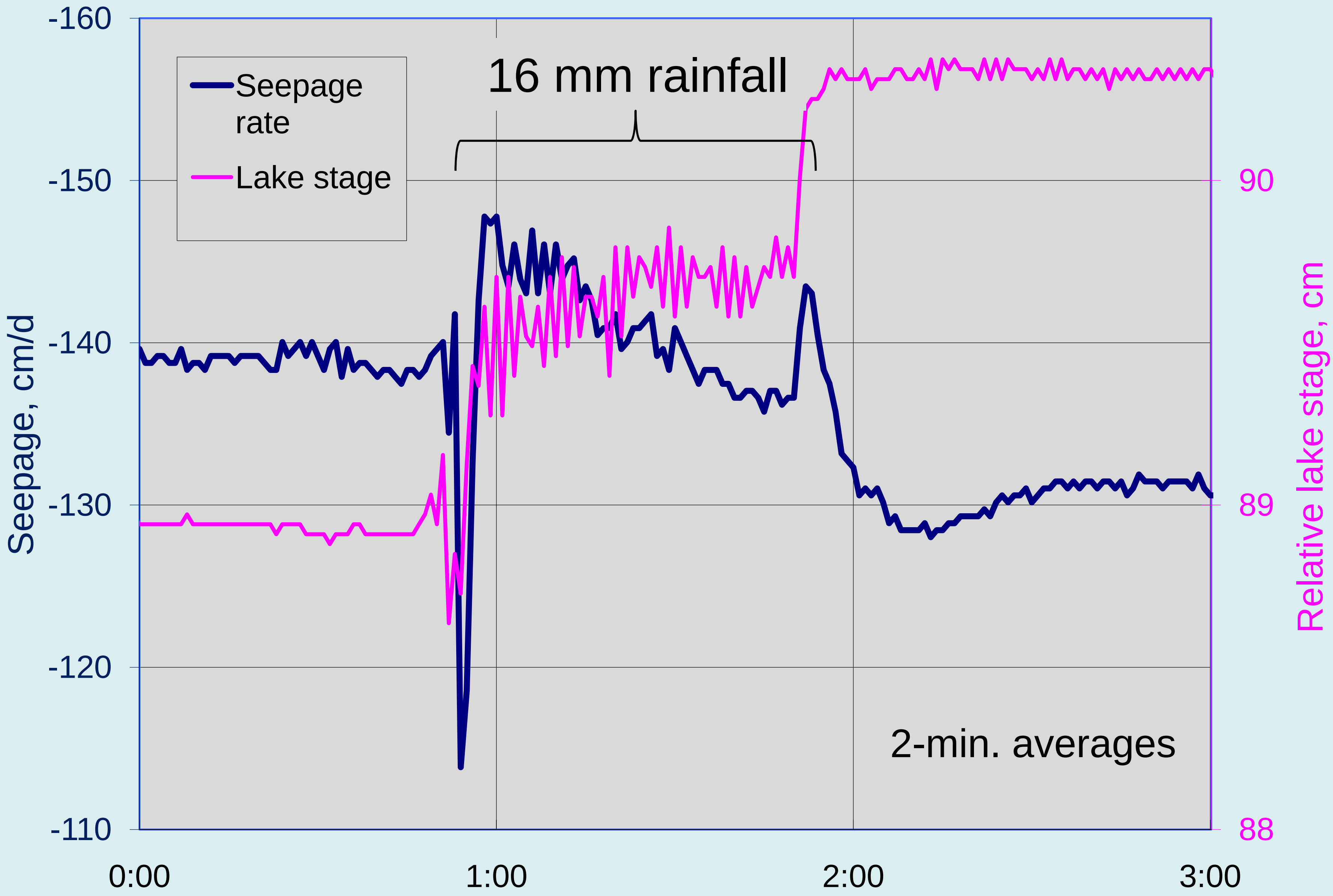
Cable et al., 2006, *Limnology and Oceanography-Methods*

Automated sensors provide much greater temporal resolution




Mirror Lake, NH
velocity meter
pressure transducer

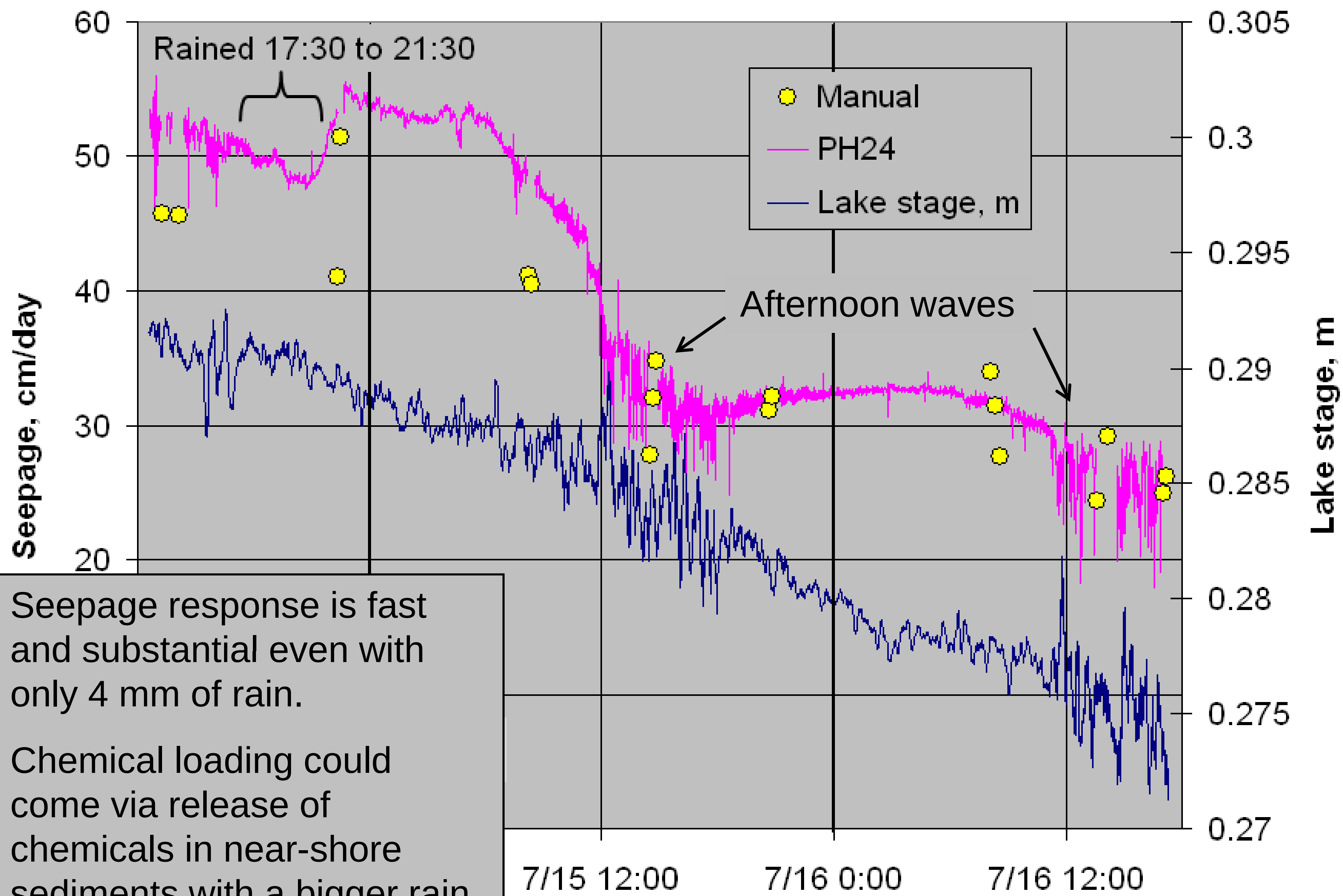
Thunderstorm and wind



Rosenberry & Morin, 2004 *Ground Water*


Ashumet Pond, MA

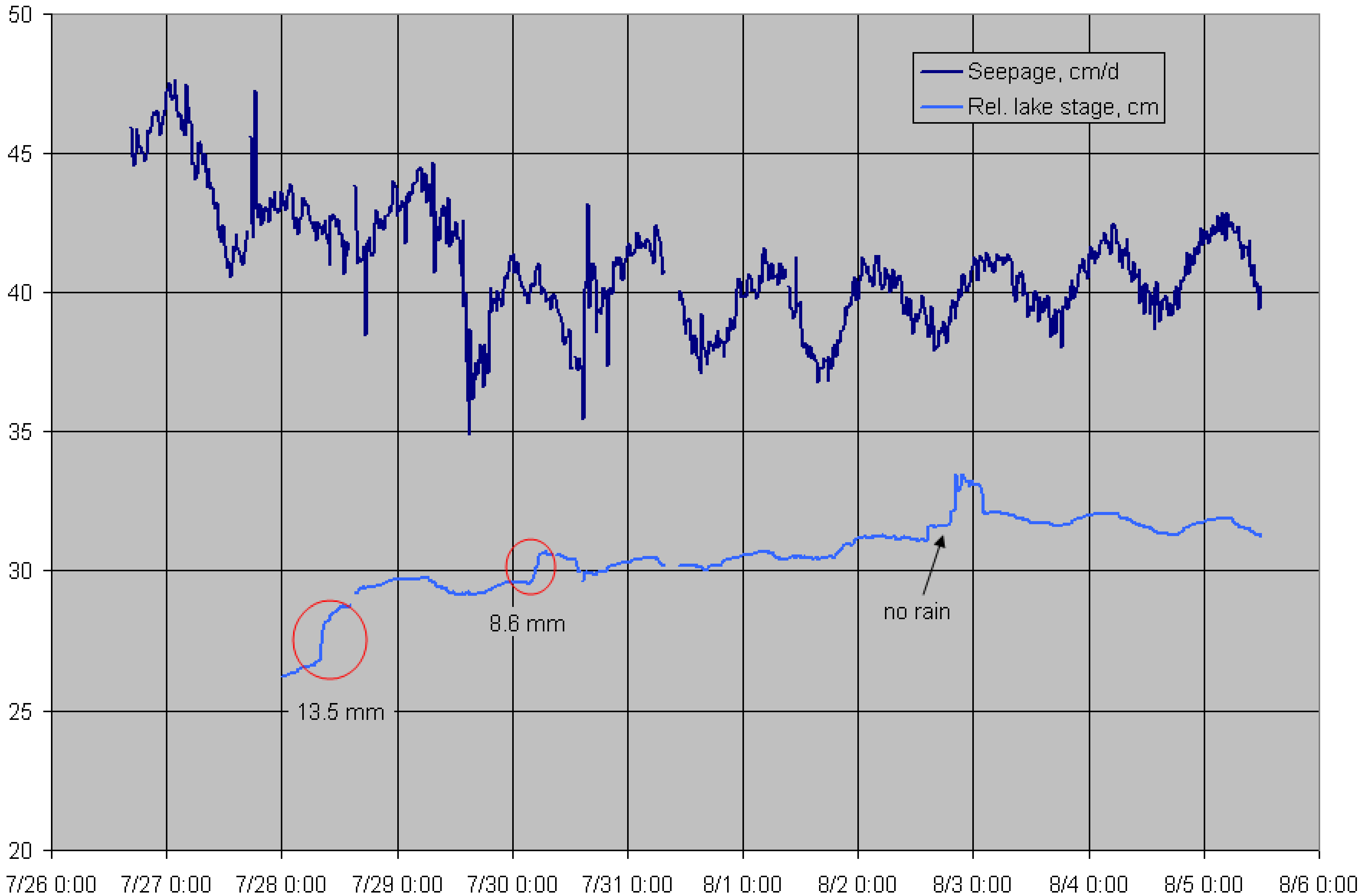
Small 4 mm rainstorm



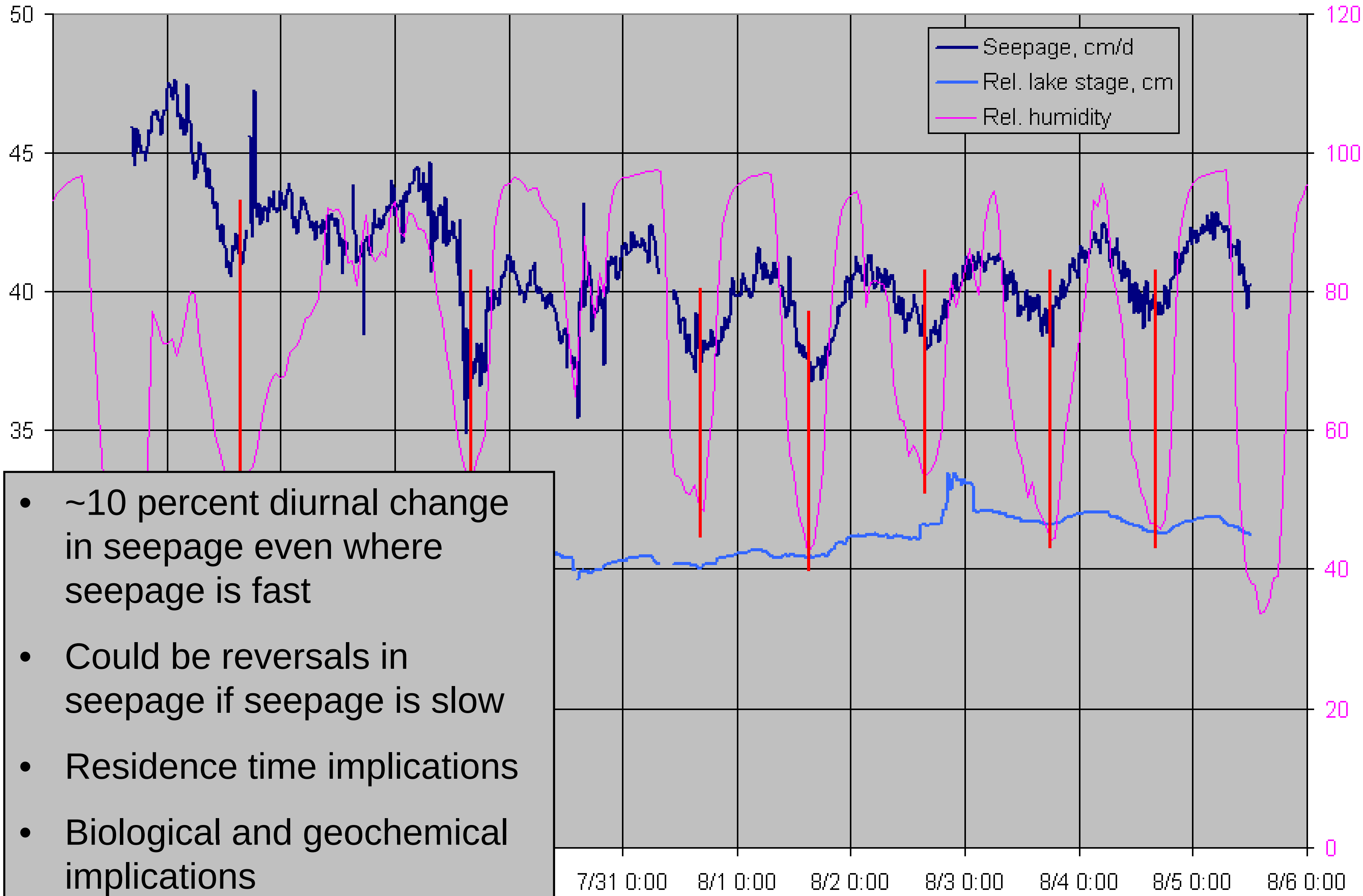
- Seepage response is fast and substantial even with only 4 mm of rain.
- Chemical loading could come via release of chemicals in near-shore sediments with a bigger rain.


Shingobee Lake, MN

Evapotranspiration (and rain?)



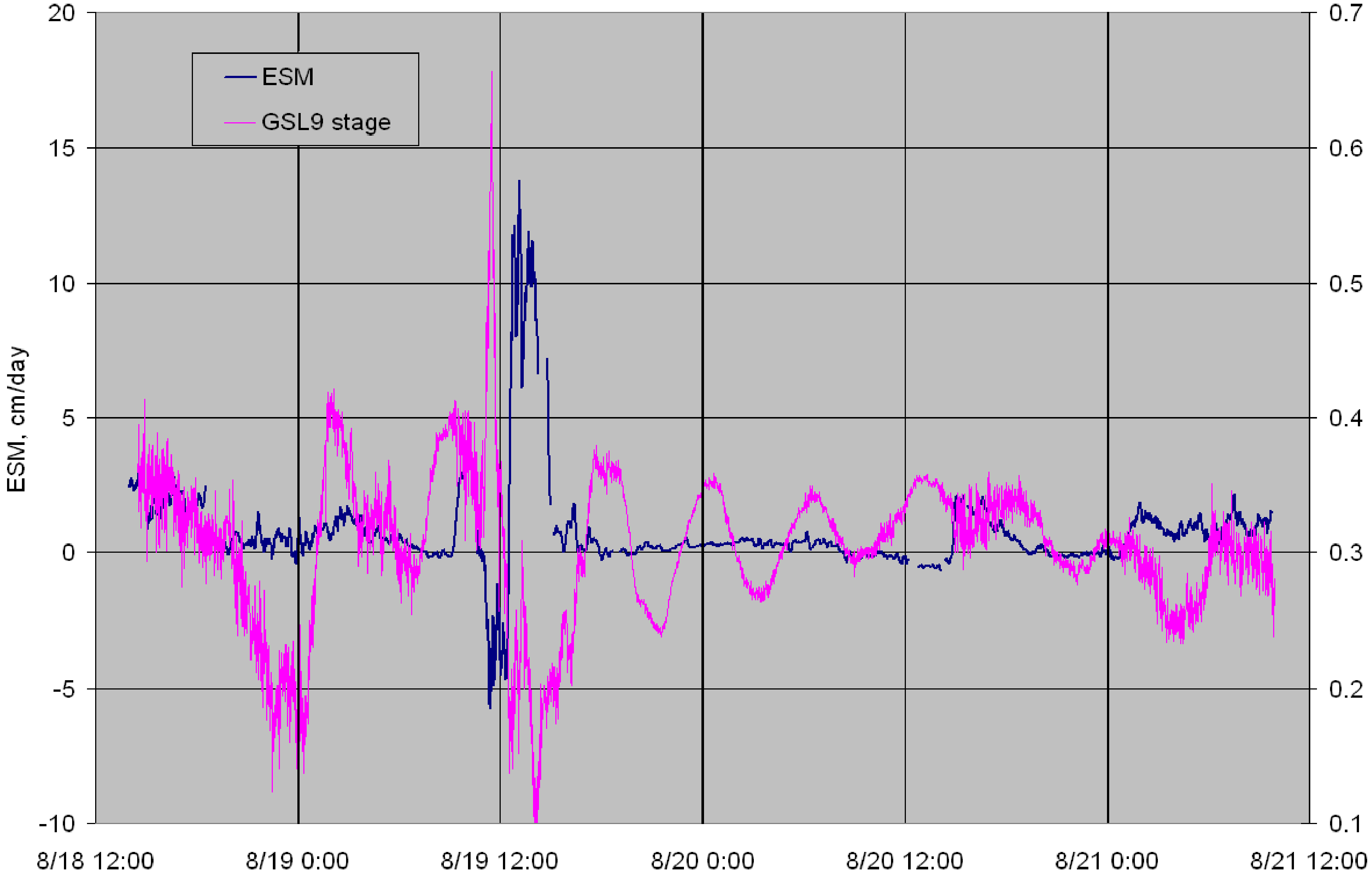
Well, maybe



- ~10 percent diurnal change in seepage even where seepage is fast
- Could be reversals in seepage if seepage is slow
- Residence time implications
- Biological and geochemical implications

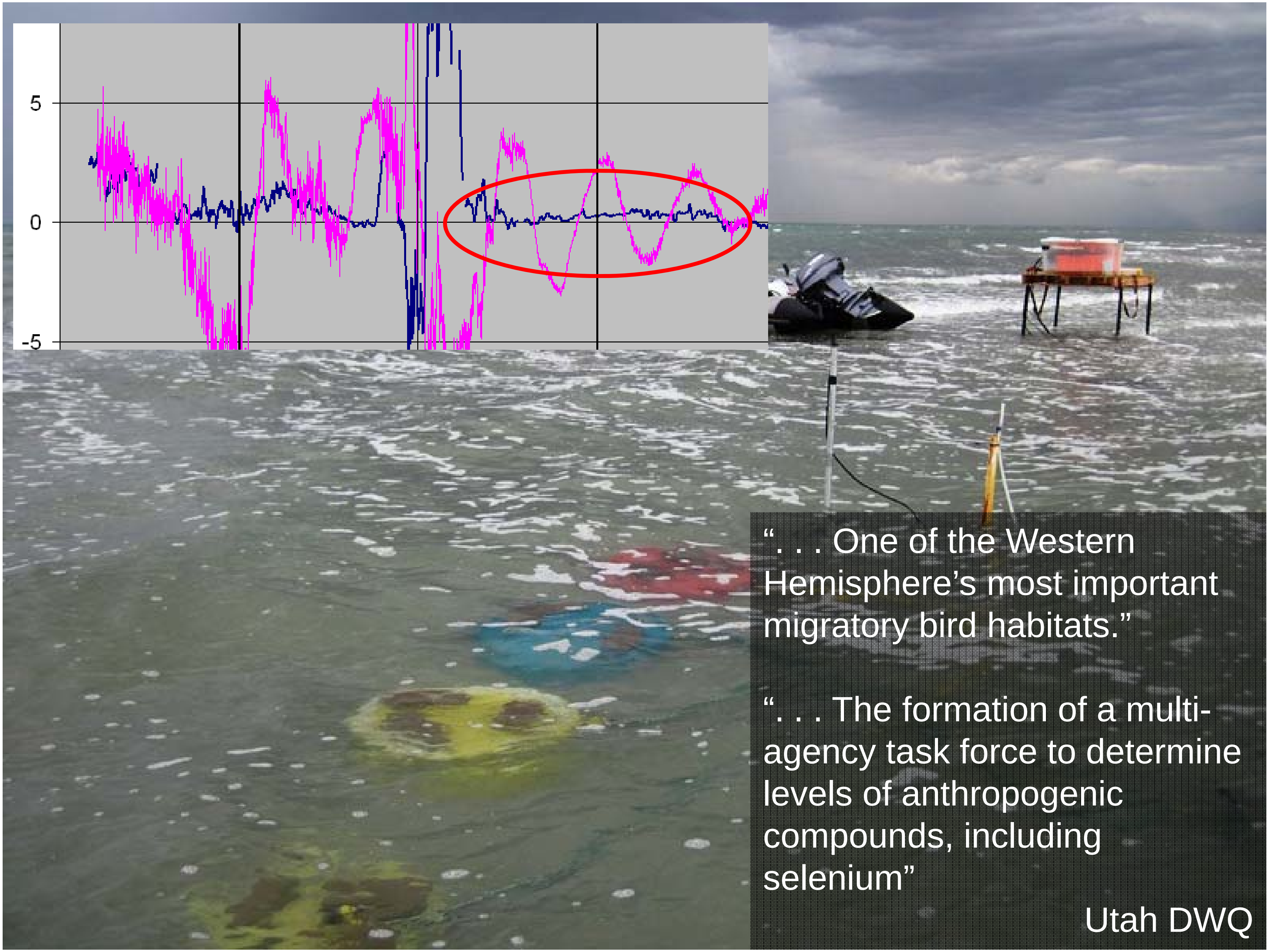

Great Salt Lake, UT

Lake seiche


ESM
GSL9 stage
ESM, cm/day
Rel. lake stage (m)
20
15
10
5
0
-5
-10
0.7
0.6
0.5
0.4
0.3
0.2
0.1
8/18 12:00
8/19 0:00
8/19 12:00
8/20 0:00
8/20 12:00
8/21 0:00
8/21 12:00

Selenium in the Great Salt Lake

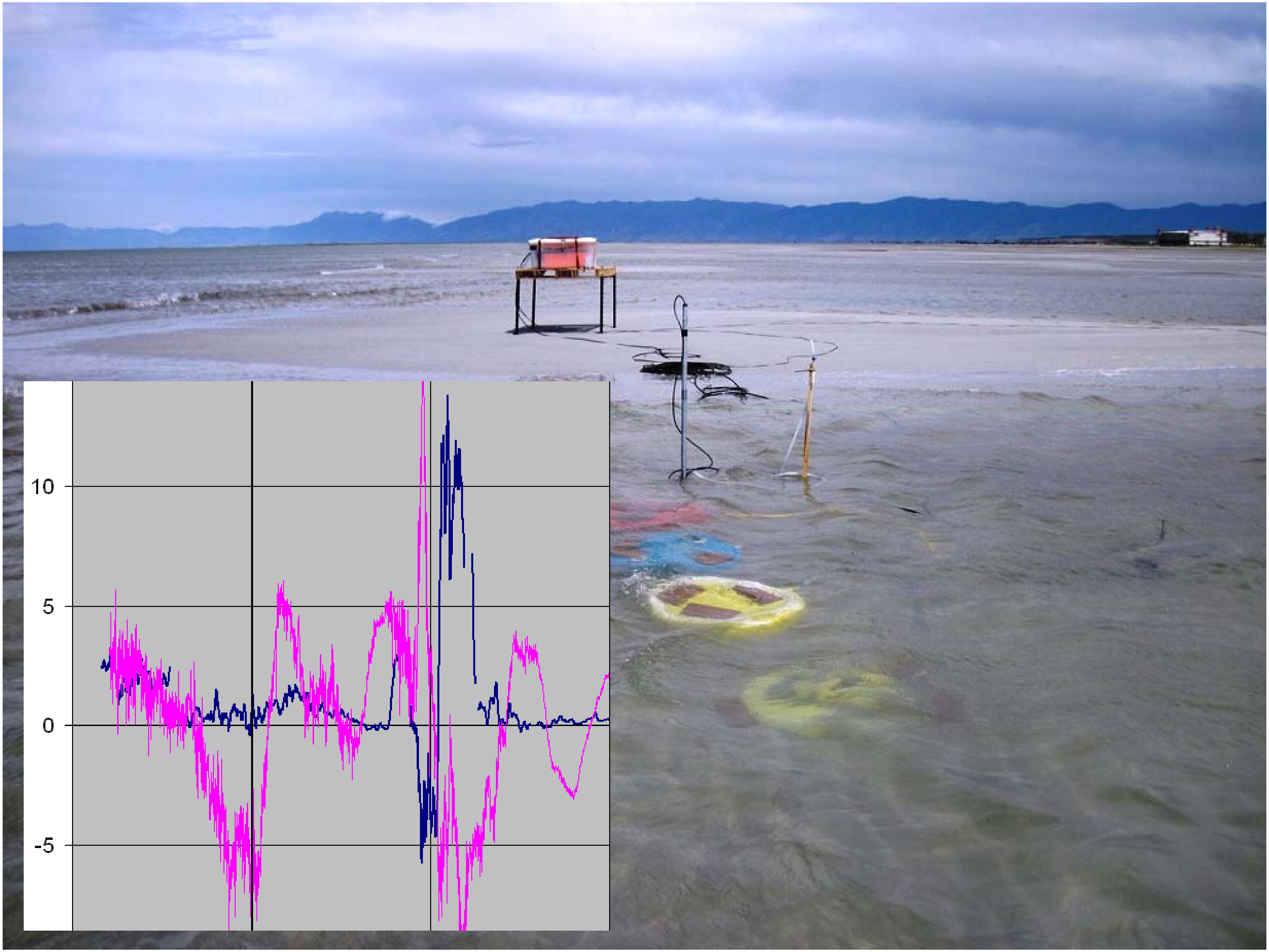
So what?



"... One of the Western Hemisphere's most important migratory bird habitats."

"... The formation of a multi-agency task force to determine levels of anthropogenic compounds, including selenium"

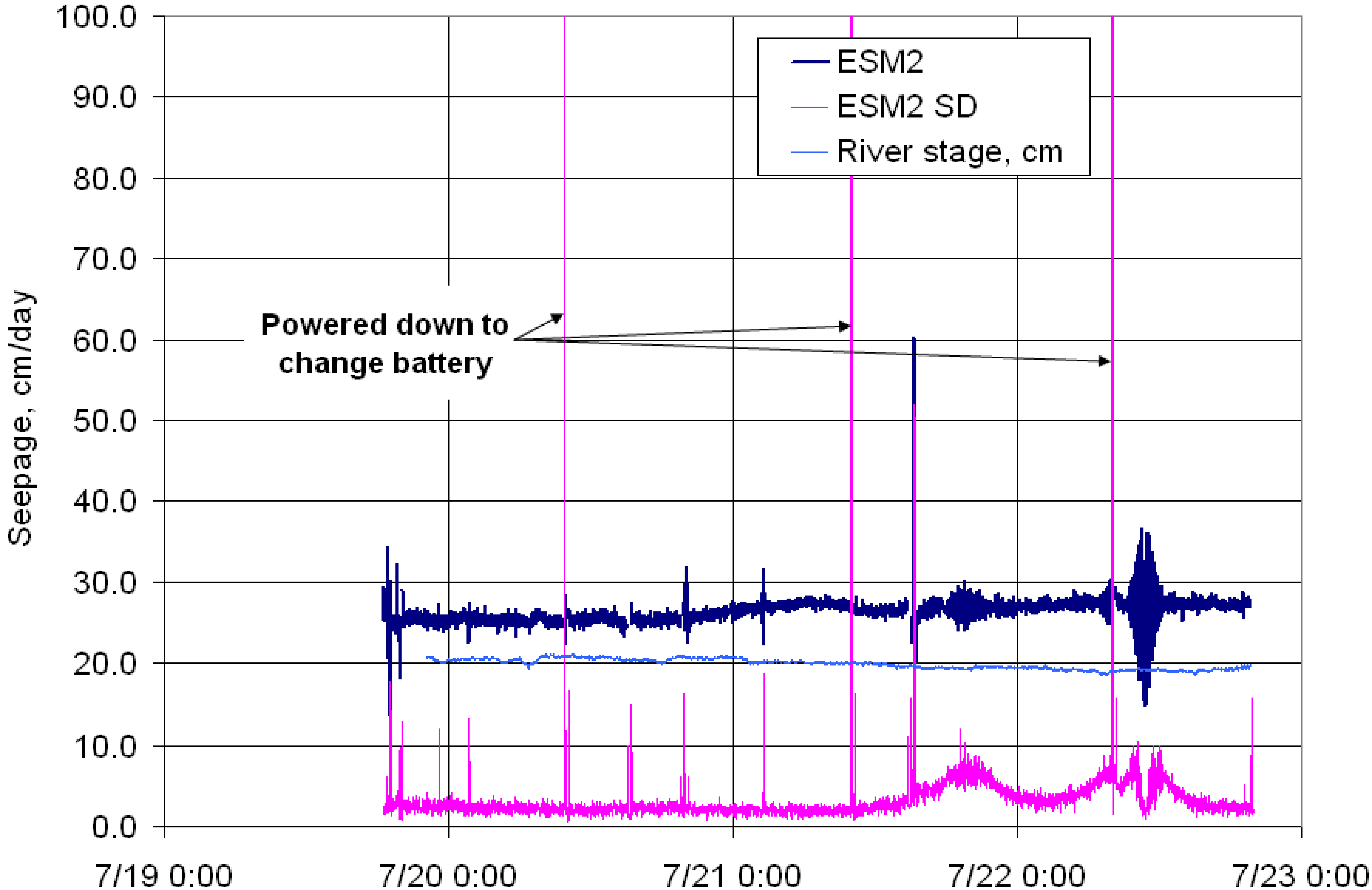
Utah DWQ



10
5
0
-5

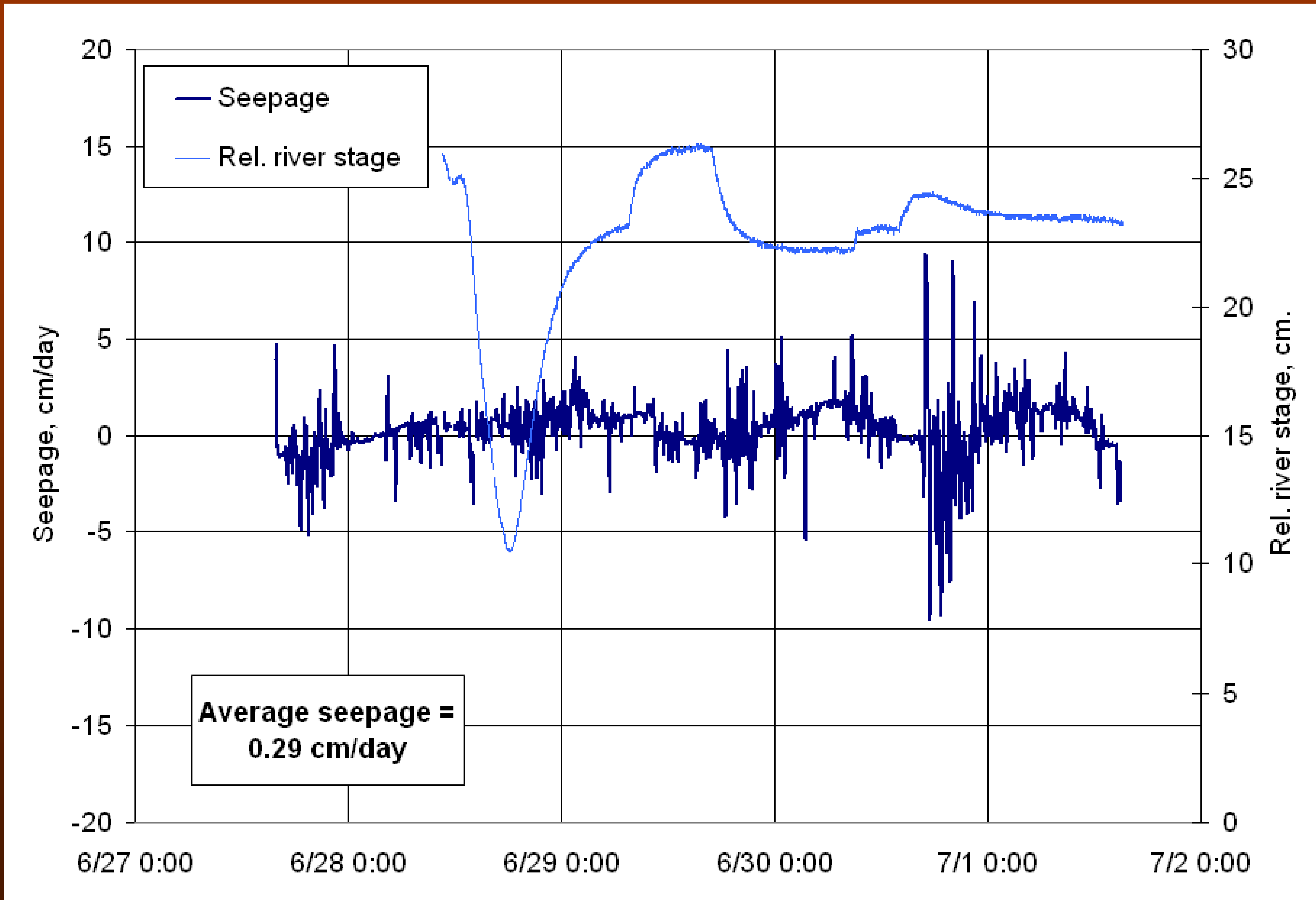

Shingobee River

Who knows?

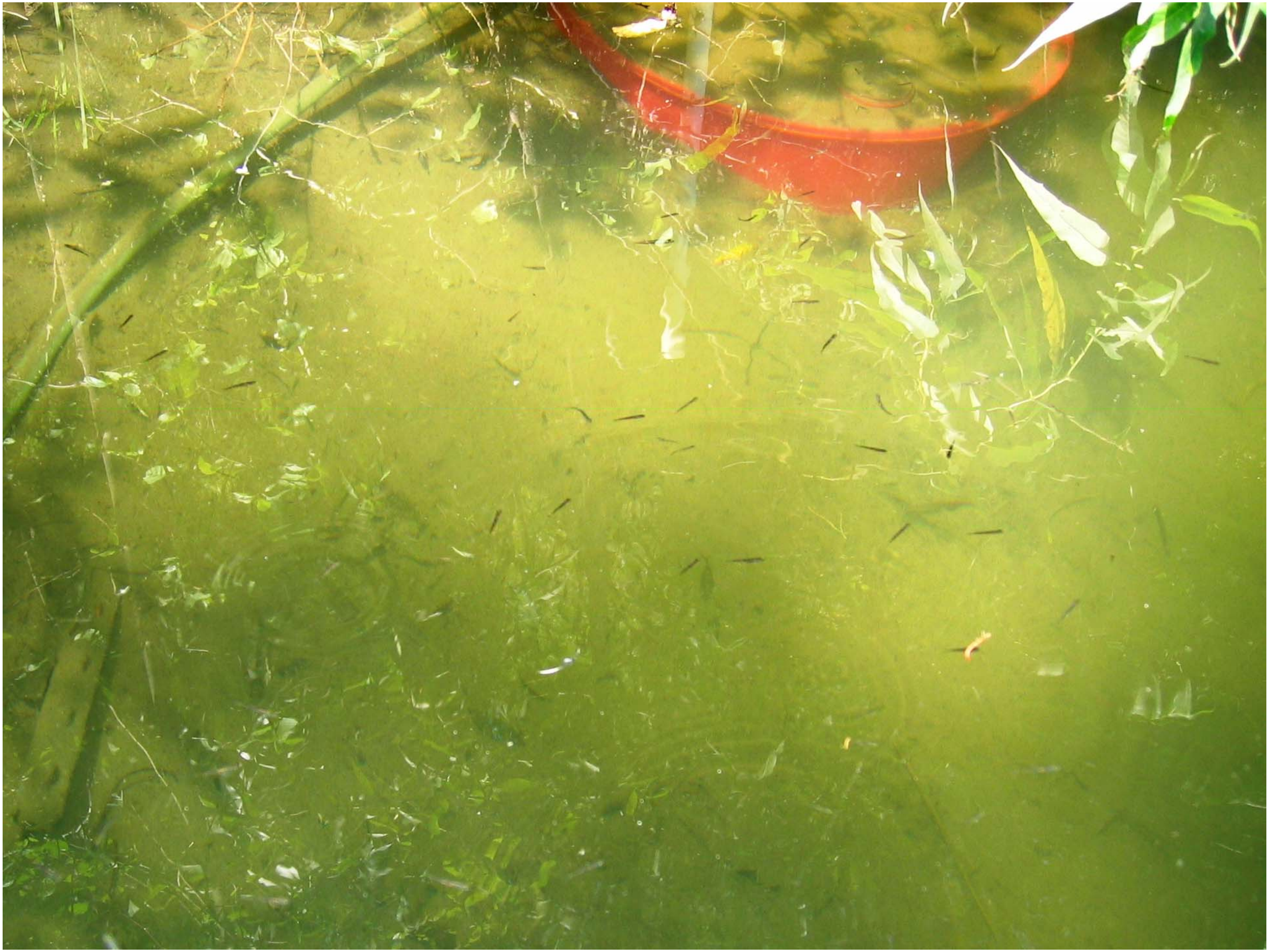


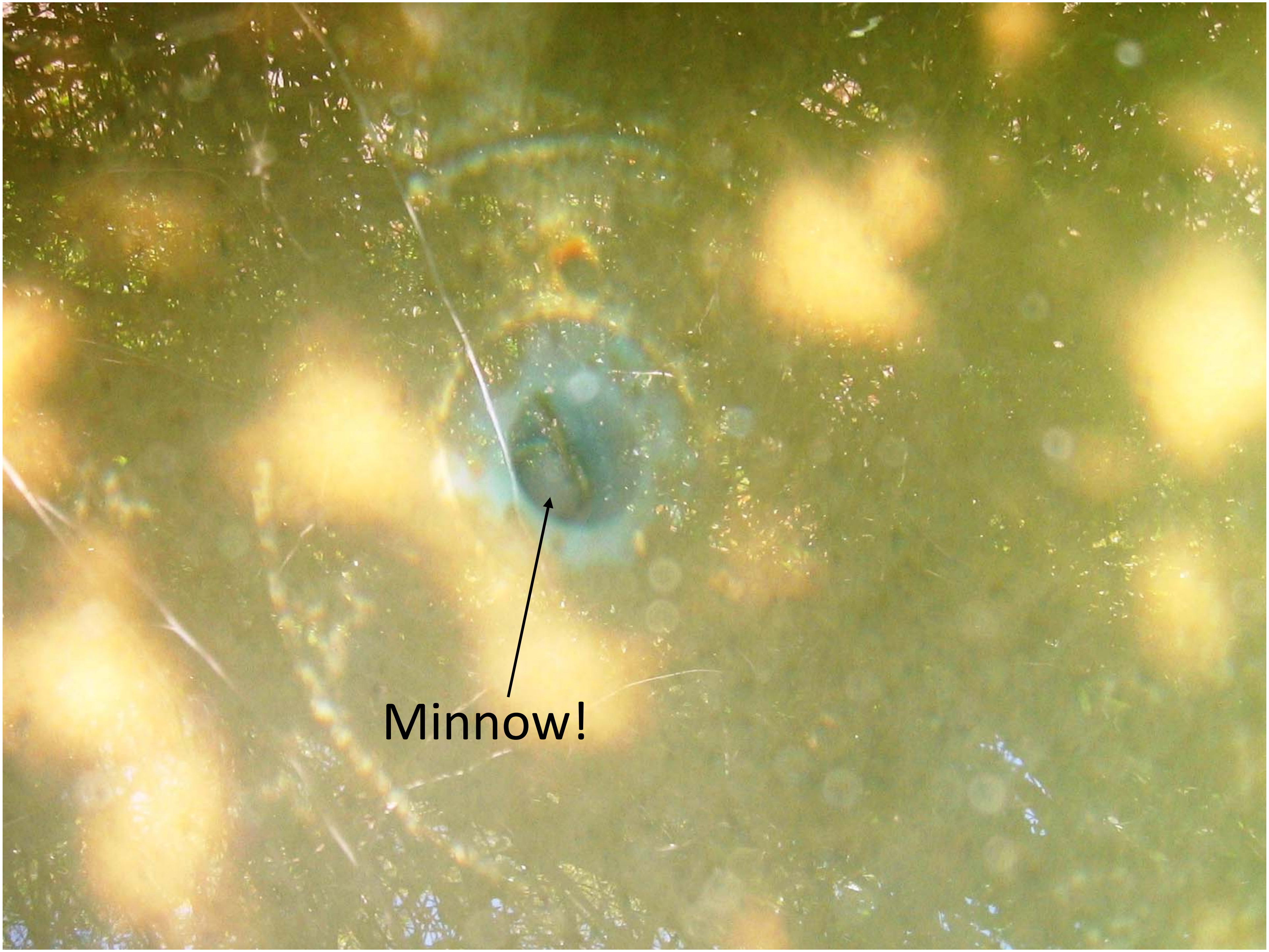
ESM2
ESM2 SD
River stage, cm
Powered down to
change battery
Seepage, cm/day
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
7/19 0:00
7/20 0:00
7/21 0:00
7/22 0:00
7/23 0:00


Russian River, CA



Seepage
Rel. river stage
Average seepage =
0.29 cm/day
Seepage, cm/day
Rel. river stage, cm.
20
15
10
5
0
-5
-10
-15
-20
30
25
20
15
10
5
0
6/27 0:00
6/28 0:00
6/29 0:00
6/30 0:00
7/1 0:00
7/2 0:00

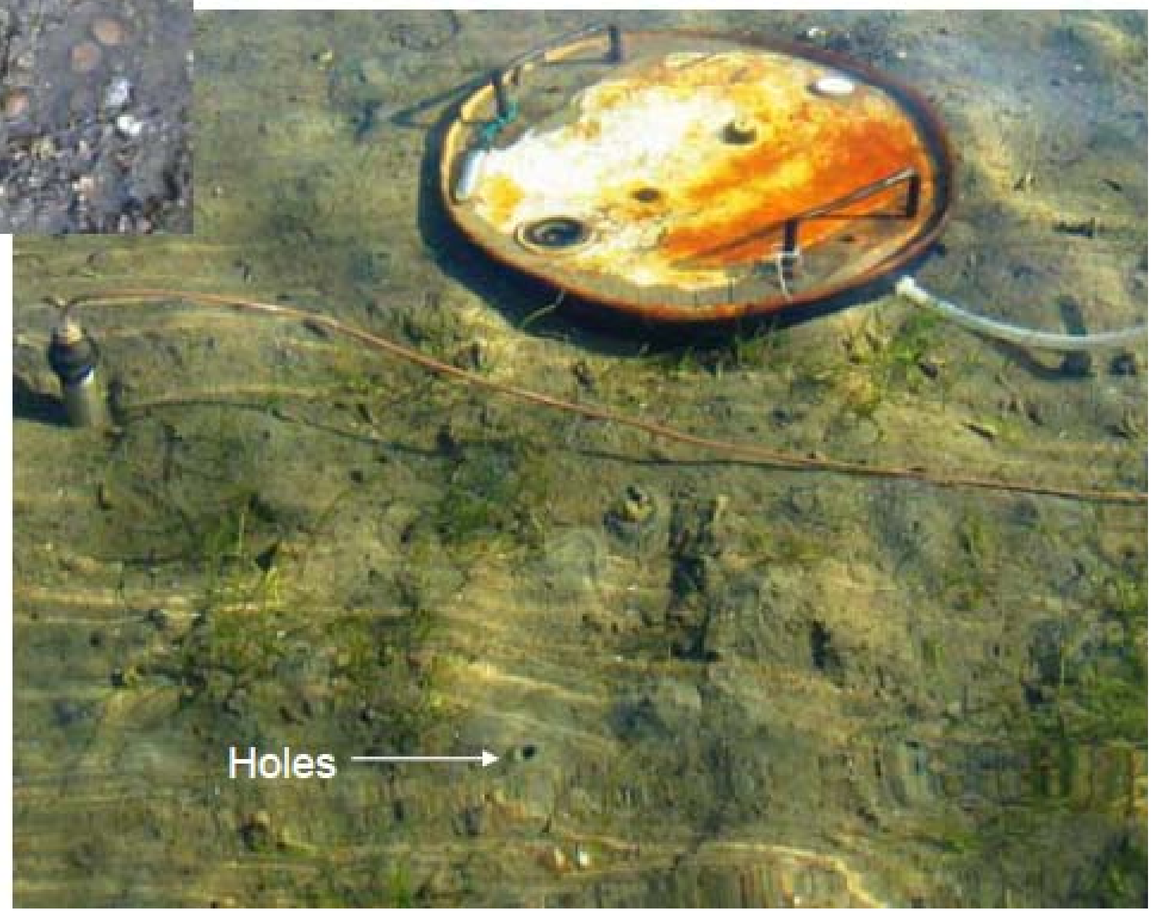



Minnow!

Bioirrigation

Bioirrigating organism		Linear velocity, cm day^{-1}
Common name	Species	
Ghost shrimp[1]	*Callianassa sp.*	0.2
Mud shrimp[2]	*Upogebia affinis* (?)	2.2
Lugworm[3]	*Arenicola marina*	1.6
Plumed worm[4]	*Diopatra cuprea*	1.3
		5

Cable et al., 2006, L&OM



Spawning redds

Alexander and Caissie. 2003. *Ground Water*

Brown and Ford. 2002. *River Research and Applications*

Moir et al. 2002. *Geomorphology*

Morrison et al. 2002. *Journal of Hydrology*

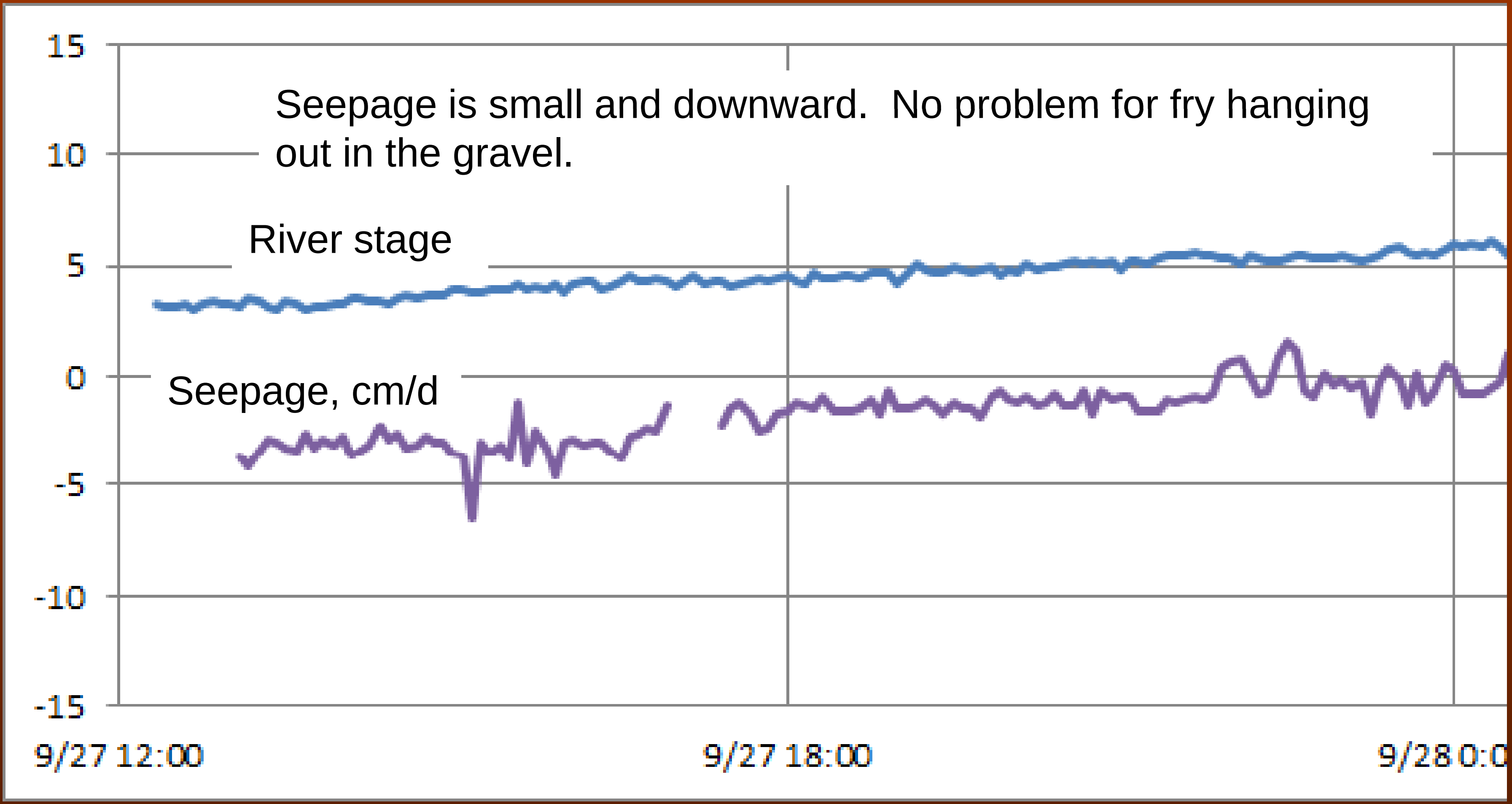
Soulsby et al. 2001. *Regulated Rivers: Research & Management*

Baxter and Hauer. 2000. *Journal of Fisheries and Aquatic Science*

Baxter and McPhail. 1999. *Canadian Journal of Zoology*

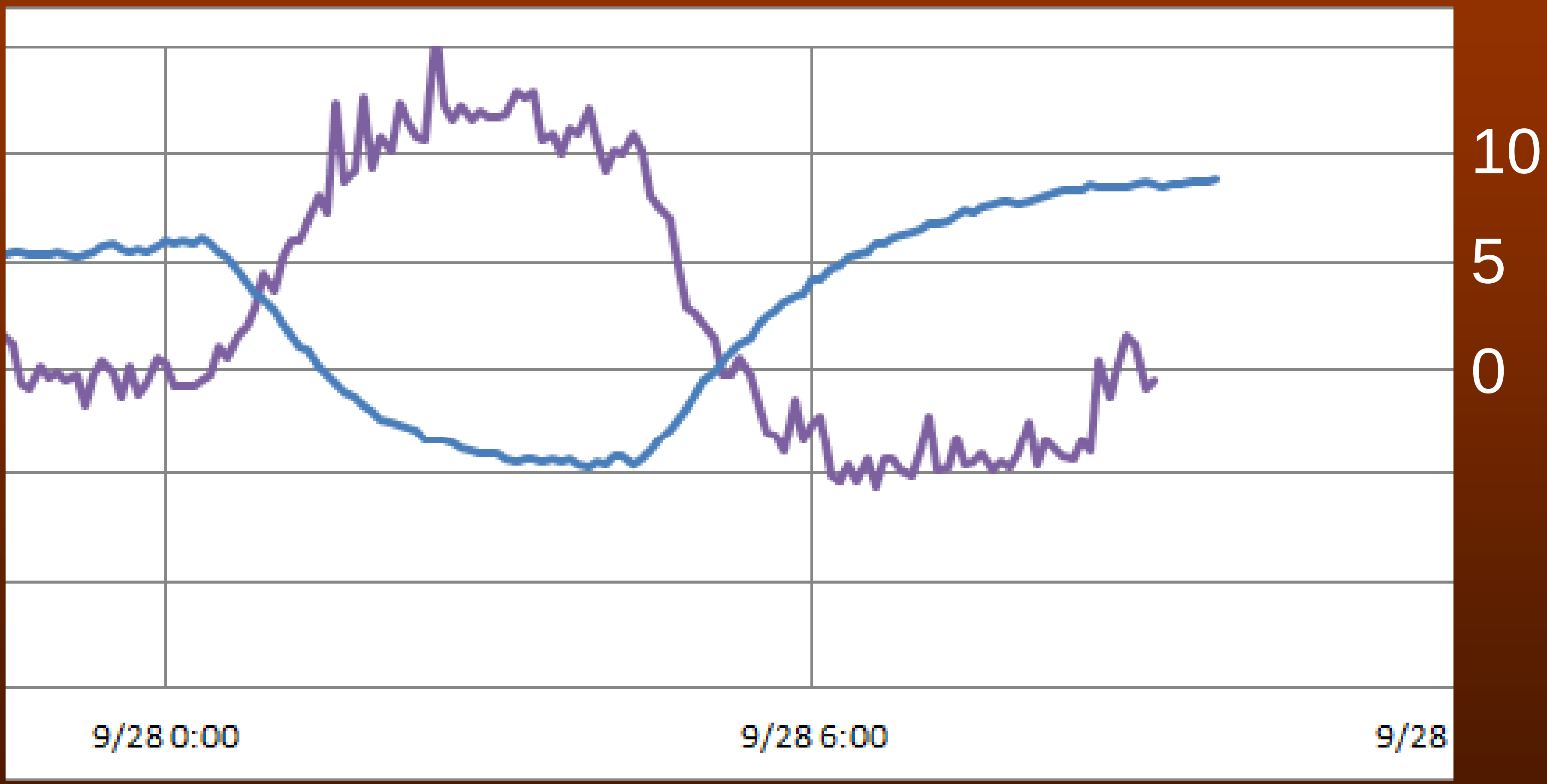
Garrett et al. 1998. *Journal of Fisheries Management*

Pitlick and Van Steeter. 1998. *Water Resources*



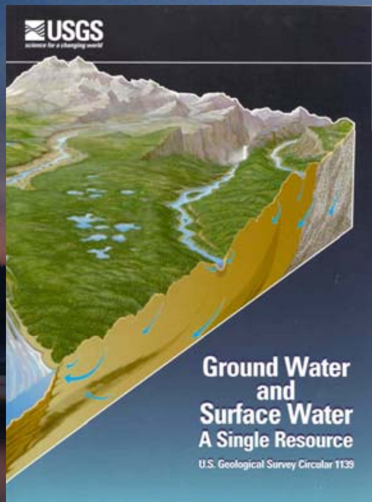
Seepage is small and downward. No problem for fry hanging out in the gravel.
River stage
Seepage, cm/d
15
10
5
0
-5
-10
-15
9/27 12:00
9/27 18:00
9/28 0:0

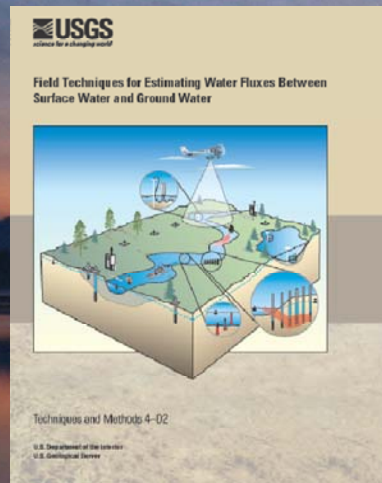
Until nighttime when river stage drops and seepage becomes upward



So who cares?

Plants
Benthic invertebrates
Endangered species
Fish
Ecologists
Geochemists
Geomorphologists
Engineers (and water suppliers)
Hydrologists and hydrogeologists
Resource managers

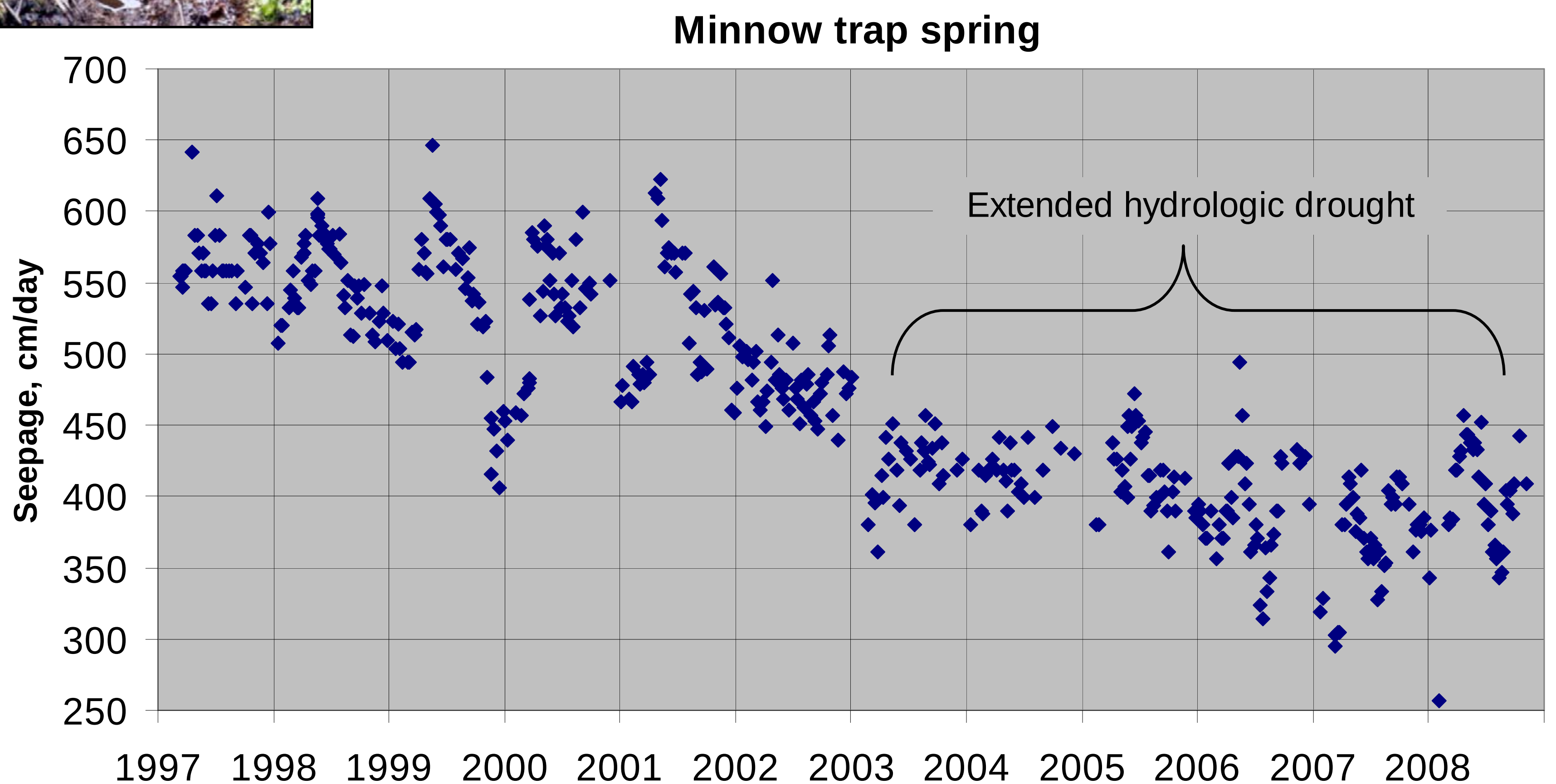




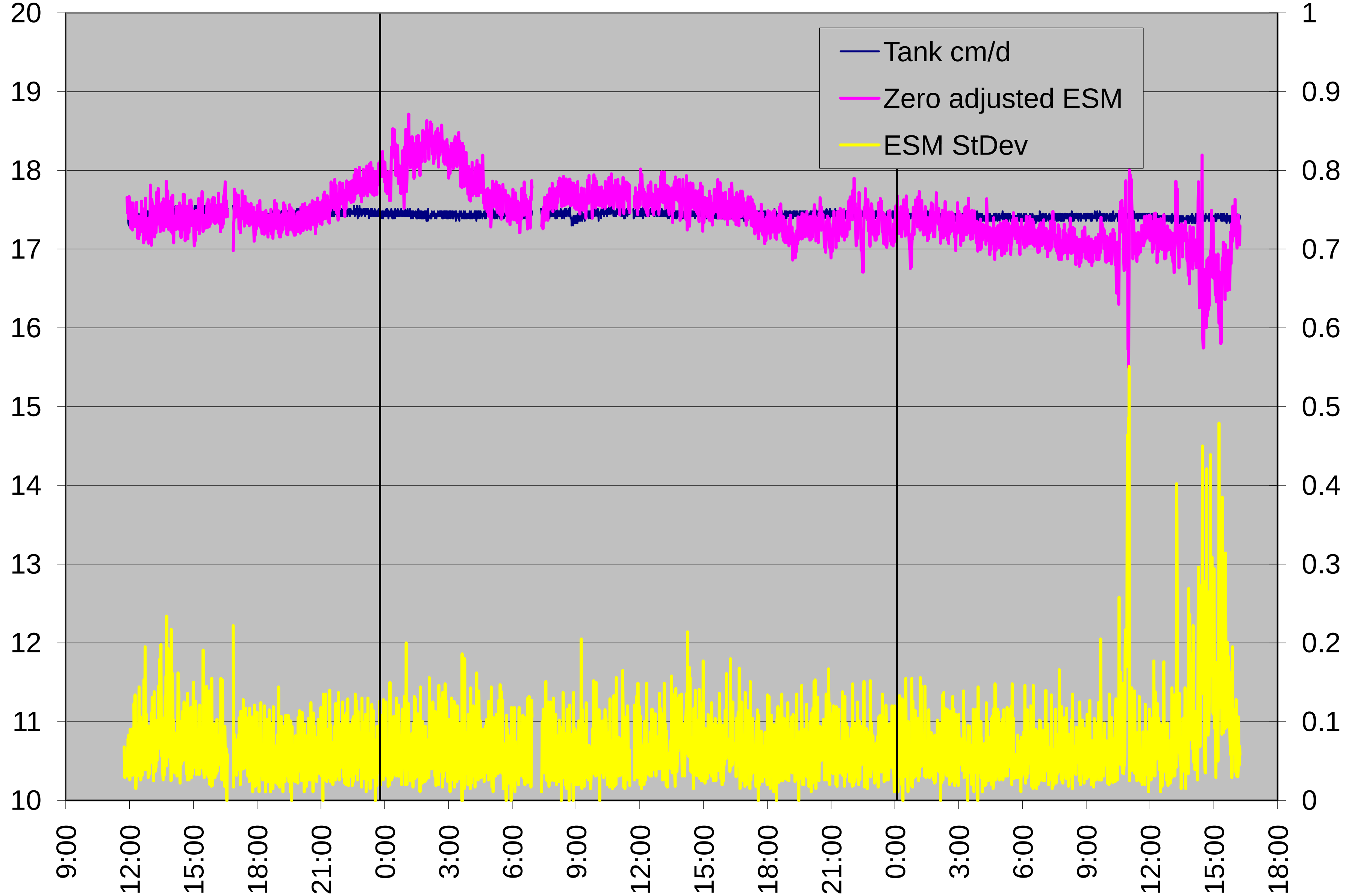
Thanks to:

- Zion Klos, Univ. of Idaho
- Andy Neal, Kansas State Univ.
- Beth Kochevar, Colorado College
- Josh Koch, USGS-Anchorage
- Denis LeBlanc, USGS Mass. WSC
- Dave Naftz, USGS Utah WSC
- Bill Simonds, Steve Cox, Rich Sheibley, USGS Washington WSC
- Perry Jones, USGS Minnesota WSC
- Dallas Hudson, USGS-Shingobee Field Station

But seepage can vary substantially over time in some places



Output in a controlled environment




Tedious and labor intensive
When will it ever end!?
USGS


A better way
Rosenberry, 2005,
Limnology and Oceanography-Methods.